1977

Sex Differences In Functional Brain Asymmetry After Damage To The Left And Right Hemisphere

Marian Jeannette Mcglone

Furthermore, it is still an open question, whether morphological characteristics form the basis of subsequent functional specialization in the brain. No study has yet demonstrated a relationship between degree or direction of anatomical asymmetry and degree of asymmetry for speech or nonspeech functions. Not all speech zones show the left-hemisphere advantage predicted on the basis of functional specialization. It is puzzling, for instance, why the frontal operculum, traditionally defined as expressive speech zone (see Penfield & Roberts, 1959), appears larger on the right. Moreover, morphological asymmetries in the temporal lobe region, similar in direction to those reported in humans, have recently been found in primate brains, i.e., in species for whom no apparent natural language has developed (LeMay & Geschwind, 1975; Yeni-Komshian & Benson, 1976). These inconsistencies suggest that anatomical asymmetries may not, in fact, be as systematically related to functional specialization of the hemispheres as initially believed.

Sex differences in anatomical asymmetries are nevertheless interesting in their own right and may be pertinent to previously reported asymmetries in EEG recordings. If the male brain is, in fact, anatomically more asymmetrical than the female brain, the probability of recording over non-homologous areas from the two sides would be greater in males than in females. Thus, whether EEG asymmetries are anatomically and/or functionally based will remain unclear until more is known about the relationship be-

SEX DIFFERENCES IN FUNCTIONAL BRAIN ASYMMETRY AFTER DAMAGE TO THE LEFT AND RIGHT HEMISPHERE

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Submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

Faculty of Graduate Studies
The University of Western Ontario
London, Ontario
April, 1977

ABSTRACT

Sex differences in cerebral organization were studied by comparing male and female patients for patterns of deficits after unilateral brain lesions. After left-hemisphere damage, right-handed males were significantly more impaired than right-handed females in elementary language production and comprehension, in verbal intelligence and in verbal memory. Left- and right-hemisphere lesions resulted in mild, but significant, loss of verbal intelligence in women, but not in men, compared to normal control subjects. It was suggested that cerebral representation of speech functions may be more bilaterally organized in right-handed females than in right-handed males.

After right-hemisphere lesions, nonverbal intelligence was impaired, relative to verbal, in men but not in women. It was suggested that males may be more right-hemisphere dependent than females for nonverbal functions, in parallel with their greater left-hemisphere dependence for verbal functions.

These sex differences were not accounted for by other variables such as age, education, extent, locus or etiology of the brain lesion, or to incidence of familial sinistrality. Overall, the data suggested greater hemispheric specialization for both verbal and nonverbal functions in the adult male than in the adult female.

ACKNOWLEDGEMENTS

For her helpful guidance and support, particularly during the preparation of the manuscript, and for the numerous clinical and research opportunities that she has provided for me, I most gratefully thank Doreen Kimura, my chief advisor. Improvements to earlier drafts of the thesis coming from Jonathan Lomas, Ron Kramis, Katy Mateer, Terry Robinson and Richard Harshman were much appreciated. Some of the testing was completed by Elaine Dunn, Hope Evenden, Walter Heywood and Katy Mateer. A special note of thanks is forthcoming to Elaine, Hope and Jonathan who took on an extra clinical load and thus permitted me the time to write up the thesis. Without Mary-Jean Novlans' unsurpassed typing skills and patience, this work would have progressed at an even slower pace.

My appreciation is also expressed to members of the Clinical Neurological Sciences and Rehabilitation departments, University Hospital, London, Canada, for the opportunity to study their patients. This project was assisted by an Ontario Mental Health Foundation Studentship and by grants to Dr. Kimura from The Medical Research Council and The National Research Council, Ottawa.

Finally, recognition is due to my young son, Warren, who bore with me during difficult times and whose very existence has helped to place the "graduate school experience" in a healthier perspective.

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INTRODUCTION

One of the most striking characteristics of the human brain is its asymmetrical control of verbal and spatial processes. The term, "functional brain asymmetry" refers to the fact that there is complementary specialization of function in the two cerebral hemispheres, whereby the left side controls speech functions and the right side is predominant for nonverbal, visuospatial functions (for review, see Kimura, 1973; Milner, 1975; Mountcastle, 1962; Piercy, 1964). This pattern holds for most right-handers, although children and left-handers show a lesser degree of hemispheric specialization for speech functions than do right-handed adults (Basser, 1962; Hécaen & Sauget, 1971).

This thesis is primarily concerned with the influence of sex in the cerebral lateralization of verbal and nonverbal functions. Before discussing sex differences in brain asymmetry, however, a brief review of clinical and normative methods from which asymmetry in hemispheric specialization has been inferred will be given.

Functional brain asymmetry

The assumption underlying clinical research on unilaterally brain-damaged patients is that psychological deficits seen after localized lesions provide a valid source of information regarding the functioning of the affected region, in the healthy brain. Thus, patterns of psychological deficits seen after left- and right-hemisphere damage have been compared to determine which functions appear more dependent on one side of the brain than the other.

The original suggestion that the two cerebral hemispheres were not functionally equivalent came from observations by Dax in 1836, and later by Broca, that linked speech disorders, i.e., aphasia, with left- rather than right-brain damage (see Penfield & Roberts, 1959). But another neurologist, Hughlings Jackson (1874), first noted that patients with right-hemisphere damage displayed exaggerated difficulties with visual perception, despite intact language skills.

With the converging of neurology and psychology, the literature on hemispheric specialization has advanced in terms of test sophistication, application of experimental methodology and the emergence of statistical analysis of data collected on large samples of patients (see Weisenberg & McBride, 1935). Thus, left-sided brain lesions have been found to be associated with a higher incidence and greater severity of aphasic disorders than right-sided lesions (Russel & Espir, 1961; Subirana, 1969), and in the absence of outright aphasia, with impairments in verbal intelligence (Anderson, 1950; 1951; Milner, 1975; Reitan, 1955), verbal memory (Milner, 1975), reading and writing (Weisenberg & McBride, 1935). In contrast, nonverbal deficits tend to be more common and more severe after right- than left-brain damage. These have been found to include: depressed Performance IQ -- a measure of nonverbal intelligence -- (Anderson, 1950; 1951; Vega & Parsons, 1969; Warrington & James, 1967a); impaired nonverbal memory (Kimura, 1963a; Milner, 1968); unilateral neglect of space, topographical disorientation, perceptual and visuoconstructional difficulties (Benton, 1962; 1967; Hécaen, 1967; McFie et al., 1950; Warrington & James, 1967a); impairments in the discrimination of colour (De Renzi & Spinnler, 1967); the enumeration of scattered objects (Kimura, 1963a; McFie et al., 1950; Warrington & James, 1967b); the perception of depth (Benton & Hécaen, 1970; Carmon & Bechtoldt, 1969); faces (De Renzi & Spinnler, 1966; Hécaen and Angelergues, 1962; Warrington & James, 1967c), and pitch and tonal patterns (Milner, 1967).

Thus, until recently, the principle source of knowledge about the division of labour between the two cerebral hemispheres had been the effect of disease, trauma or surgery on psychological functions. However, special techniques have made it possible to study some aspects of functional asymmetry in non-brain-damaged subjects, using dichotic listening procedures in the auditory modality and tachistoscopic procedures in the visual modality.

Dichotic listening studies, in which different auditory stimuli are presented simultaneously to the two ears, have revealed consistent right-ear advantages for verbal material such as digits, words and consonant-vowel syllables (Kimura, 1961; 1967; Darwin, 1971; Shankweiler & Studdert-Kennedy, 1967). Conversely, a left-ear advantage has been obtained for the recognition of nonverbal sounds (Curry, 1967; Kimura, 1964; Knox & Kimura, 1970; Spreen et al., 1970). The assumption underlying dichotic experiments is that, although there are crossed and uncrossed pathways to each hemisphere, the crossed pathways have more numerous and effective connections with the contralateral hemisphere than do the ipsilateral pathways (Rosenzweig, 1951; Tunturi, 1946). Thus, the advantage of one ear over the other in identifying particular auditory stimuli has been interpreted as reflecting specialization in the contralateral hemisphere for that function (Kimura, 1961; 1967).

In the visual modality, the differential recognition of material presented tachistoscopically to the left or to the right of central fixation also depends upon the verbal-nonverbal nature of the stimuli, in a manner consistent with auditory laterality effects. A right-visual field advantage has been demonstrated for the perception of words and letters (Bryden, 1965; Kimura, 1966; Bryden, 1973; Mishkin & Forgays, 1952), suggesting greater left-hemisphere processing of verbal functions. In contrast, nonverbal stimuli -- previously demonstrated to be more right- than left-hemisphere dependent -- yielded left-visual field superiorities, specifically for the location of a dot in space (Kimura, 1969), the enumeration of scattered stimuli (Kimura, 1966; McGlone & Davidson, 1973), the perception of line slant (Kimura & Durnford, 1974) and depth perception (Durnford & Kimura, 1971). The visual system is so organized that stimuli presented in the left visual field project to the right hemisphere, whereas stimuli presented to the right of fixation are transmitted to the left hemisphere. Thus, superior performance in one hemifield has been interpreted as supporting the idea of functional specialization in the contralateral hemisphere (Kimura, 1966).

Electrophysiological recordings of brain wave activity have also been used to investigate hemispheric specialization in normals. Such procedures involve evoked potential recordings (Buchsbaum & Fedio, 1969; Cohn, 1971; Molfese et al., 1975), and electroencephalographic (EEG) measures of alpha wave dyssynchrony

(McKee et al., 1973). Auditory language stimuli elicit a lateralized pattern of evoked responses favouring the left hemisphere, whereas nonlanguage auditory stimuli elicit a lateralized pattern favouring the right hemisphere (Cohn, 1971; Molfese et al., 1975). Interpretation of these results in terms of functional brain asymmetry depends on the assumption that a difference in level or pattern of electrical activity between left and right sides reflects the extent to which each hemisphere of the brain is involved in processing the stimuli.

Sex differences in functional brain asymmetry

For more than 30 years, it has been known that levels of verbal and spatial abilities differ between men and women, with a female superiority on certain language-related tasks, and a male superiority on spatial tasks (for review, see Maccoby, 1966; Maccoby & Jacklin, 1974). But it was not until 1961 that Herbert Lansdell first reported differences between males and females in the left-right organization of cognitive functions in the brain (Lansdell, 1961), and most recently, Buffery & Gray (1972) have attempted to account for sex differences in overall cognitive ability on the basis of a brain lateralization model.

However, the direction of sex differences in brain lateralization proposed by Buffery & Gray (1972) stand in direct opposition to those reported by Lansdell (1961; 1962; 1968a; 1973).

Whereas Lansdell concluded that male brains may be more asymmetrically organized than female brains, for nonverbal functions at least, just the opposite view is held by Buffery & Gray, who claimed that female brains were liable to be more lateralized compared to male brains, for both verbal and nonverbal functions. In the following sections, the clinical and normative data on which these contrasting views have been based will be examined to determine which, if either, is correct. The review focuses upon studies containing adult right-handers and omits single case studies and articles containing data on only one sex.

Clinical studies

One way to examine the effects of sex on functional brain lateralization is to contrast residual verbal skills with residual nonverbal skills after left- and right-brain damage. Lansdell & Urbach (1965) compared ratio scores based on seven so-called "nonverbal" subtests (Digit Span, Arithmetic, Picture Completion, Block Design, Object Assembly, Picture Arrangement and Digit Symbol) and four "verbal" subtests (Information, Comprehension, Similarities and Vocabulary) from the Wechsler-Bellevue Scale of Intelligence. In men, left temporal lobectomies produced relatively impaired verbal to nonverbal skills, whereas right temporal lobectomies produced relatively impaired nonverbal to verbal skills. In women, there were no significant differences in nonverbal/verbal ratio scores between left- and right-hemisphere damaged cases.

These findings support the hypothesis of greater hemispheric specialization in males than in females, but fail to specify which function (verbal, nonverbal, or both) may be represented more asymmetrically in the male brain.

Verbal functions

Lansdell (1961) found that proverb interpretation was disturbed by left temporal lobe lesions in men, but not in women. Similar sex-dependent asymmetries were reported on a word association test after left thalamotomies (Lansdell, 1973). Additionally, verbal intelligence scores were negatively correlated with the size of the left temporal-lobe excision in men, but not in women, suggesting a direct relationship between amount of left-hemisphere damage and severity of verbal impairment only in men (Lansdell, 1968a). Though not explicitly stated by Lansdell himself, his studies suggest greater left-hemisphere control of verbal functions in men than in women.

Exceptions to these conclusions have been reported, but none were statistically significant. For example, on two different measures of verbal intelligence, Lansdell (1968a; 1968b) found that left-brain damaged females performed slightly worse than left-brain damaged males, while right-brain damaged males and females performed equally well. Eisenson has claimed (1967), although no actual data were ever published, that right-hemisphere lesions disrupted verbal abstraction ability in males, but not in females, compared to scores obtained by non-brain damaged controls. These reports, though statistically unverified, would predict less left-hemisphere control of complex language skills in men than in women. Finally, McFie (1975) has claimed, without presenting supporting data, that there were no differences between males and females with left- or right-hemisphere lesions in subtest patterns of verbal intelligence.

Obviously, no general consensus has been reached regarding the effect of sex upon complex verbal skills after unilateral brain lesions, but a less confusing, though still not entirely convincing, picture appears with respect to the effects of sex upon more severe speech disorders designated as aphasia.

Edwards et al. (1976) administered two standardized tests of language production and comprehension to brain-damaged patients whose aphasia had lasted for at least three months after the onset of symptoms. Residual speech disorders were significantly worse in males than in females. In an acute stroke population, Brust et al. (1976) found that the aphasic sample contained more males than females, whereas the nonaphasic sample contained more females than males, but these trends were not significant. Unfortunately, neither study identified male and female patients according to side of brain lesion, nor was it clear whether damage was confined to one cerebral hemisphere.

However, if it is assumed that the aphasic disorders resulted mainly from left-hemisphere damage, then these results favour stronger left-hemisphere representation of speech functions in males than in females.

Some support for this conclusion was found by McGlone & Kertesz (1973) who reported that after left-hemisphere lesions, males performed slightly worse than females on a composite aphasia battery, but after right-hemisphere lesions, females appeared slightly more impaired than males. The trends seen in the mean scores on their aphasia battery were not, however, significant when statistically analyzed.

Overall, there is weak support for the idea that left-hemisphere control of some verbal functions may be accentuated in adult male right-handers compared to females, but this has by no means been conclusively demonstrated.

Nonverbal functions.

A number of clinical studies have provided information on possible sex differences in the cerebral lateralization of visuospatial functions. It appears that perceptual tasks involving form or pattern recognition show no systematic or lasting interaction between sex and side of brain damage. Performance on the Mooney Closure Task showed more bilateral representation in males than in females (Lansdell, 1968b); performance on the Graves

Design Judgment Task, though transitory, showed greater right-hemisphere dependence in men, in contrast to greater left-hemisphere dependence in women (Lansdell, 1962); and results from Raven's Coloured Progressive Matrices showed no obvious sex differences after lateralized brain lesions (Edwards et al., 1976; McGlone & Kertesz, 1973).

However, spatial-constructional tasks such as the Block Design and Object Assembly subtests of the Wechsler Scales appear to be more right-hemisphere dependent in men than in women (Lansdell, 1968a; McGlone & Kertesz, 1973). McFie's claim (1975) that subtests of Wechsler's Performance IQ scale did not vary according to sex cannot be evaluated since he presented no supporting data.

Stated differently, females more often than males are liable to employ left-hemisphere mechanisms in the analysis of visuoconstructional material. In support of this idea, McGlone & Kertesz (1973) reported that the correlation between Block Design and aphasia battery scores was significant only in left-brain damaged females, suggesting that only in women was elementary language ability predictive of spatial ability.

Limitations of clinical studies

Comparisons among the various clinical studies which have looked at the effects of lateralized brain lesions as a function of sex are problematic for a number of reasons. First of all, more than one author has simply failed to publish the data on which his conclusions were based, thus preventing further evaluation of the claims (Eisenson, 1967; Lansdell, 1961; McFie, 1975).

Secondly, lateralization of the cerebral lesion is unclear in most studies. Bilateral lesions are common when patient selection is based on neurological deficits affecting one hemisphere more than the other (Lansdell, 1968a; 1968b; 1973), on the presence of aphasia (Brust et al., 1976; Edwards et al., 1976) or side of speech representation (Lansdell, 1962). Such indiscriminate inclusion of bilaterally damaged cases can mask or perhaps distort the effects of sex on hemispheric specialization.

Cross study comparisons are also made difficult because the data have been based on patients with differing central nervous system pathologies. Variations in pathology result in systematic variations in a number of factors which affect performance on psychological tests, such as extent and locus of the brain lesion, age of the patient at onset of pathology and age at time of testing, surgical intervention, recovery period, and medications (Matarazzo, 1972; Meyer, 1957). Moreover, even within studies, little attempt has been made to match sex and laterality groups for extent and locus of the lesion, age, education, hand preference or familial sinistrality.

Thus, it is perhaps surprising that any sex differences in lesion effects have been found at all, and in fact some of these reports may be attributable to systematic differences between the sexes in previously mentioned uncontrolled variables. For example, the mean number of months since surgery was higher in women with left temporal lobectomies than in any other patient group (Lansdell, 1968a; 1968b), and left-sided excisions were smaller than right-sided excisions, particularly in the women (Lansdell, 1968b; Lansdell & Urbach, 1965). Thus, the fact that females with left-sided lesions did not show significant verbal deficits, whereas males did, could have been due to smaller lesions and longer post-operative recovery periods in females compared to males. Similarly, reports of significant correlations between extent of temporal lobe removals and task performance in males, but not in females, may be related to the smaller range of scores in females than in males (Lansdell, 1968a). Finally, inability to replicate earlier findings as the sample size increased and as left-handers were excluded, strongly suggests that the initial findings may have reflected the effects of uncontrolled variables, rather than real differences between males and females in functional brain asymmetry (Lansdell, 1962; Lansdell & Urbach, 1965).

In summary, only one clinical investigation has come close to providing control information necessary to make unambiguous conclusions regarding the effects of sex of the patient, side and locus of the lesion, and type of psychological deficit (McGlone

& Kertesz, 1973). The trends suggested greater asymmetrical cerebral control of verbal and nonverbal functions in men than in women, but the differences were not statistically significant.

Dichotic listening and tachistoscopic studies in normals

With such inadequate clinical data, it is necessary to rely more heavily upon normative dichotic listening and tachistoscopic studies in search of possible ~~sex~~ differences in degree of functional brain asymmetry. However, the majority of such studies in adult right-handers either failed to specify the sex of the subjects or failed to report whether sex differences were observed or investigated (for reviews see Fairweather, 1976; Harshman & Remington, 1975; Lake & Bryden, 1976).

At least four dichotic investigations have claimed that the sex of the subject did not significantly relate to degree of right-ear advantage for the perception of digits or words (Briggs & Nebes, 1976; Bryden, 1965; Carr, 1969; McGlone & Davidson, 1973). A different conclusion was reached by Dorman & Porter (1975) who reported that the right-ear effect for consonant-vowel sounds was significantly larger in right-handed women than in right-handed men. This pattern would suggest a greater degree of asymmetrical speech representation in females than in males.

In contrast, Lake & Bryden (1976) found greater asymmetrical control in men than in women. In this study, however, sex differences in ear-superiority further interacted in a complicated fashion with hand preference and familial sinistrality. Harshman et al. (1976) have confirmed Lake & Bryden's results in an entirely right-handed sample. That is, the right-ear advantage for consonant-vowel sounds was stronger and occurred significantly more often in males than in females, a pattern suggesting that speech representation is more left-hemisphere dependent in men than in women. More confidence must be placed in results leading to the latter conclusion since the supporting studies (Lake & Bryden, 1976; Harshman et al., 1976) contained at least 100 subjects and focused directly on the issue of sex differences in verbal asymmetries, whereas Dorman & Porter (1975) were concerned mainly with stuttering behaviour, and only 10 non-stutterers of each sex were tested.

Sex differences in laterality effects on nonverbal auditory tasks have not been as extensively investigated as verbal asymmetries. King & Kimura (1972) reported that the left-ear superiority in the perception of hummed melodic patterns and vocal nonspeech sounds did not vary according to sex. Similarly, Gordon (cited by Harshman et al., 1976) did not find sex-dependent laterality effects for the perception of musical chords in non-musicians. However, in musicians the left-ear effect was greater in males than in females. Thus it would appear that in musically trained individuals, males may employ right-hemisphere mechanisms more than females for the perception of tonal pattern. However, these conclusions are partially contradicted by Bever & Chiarello (1974) who found a significant right-ear effect in musicians (sex unreported) for the perception of melodic patterns.

Thus, dichotic studies in normals do not permit any conclusive statements about sex differences, but suggest perhaps a greater ear asymmetry in males than in females.

Several recent tachistoscopic studies have indicated that laterality effects for both verbal and nonverbal material differ systematically between sexes. For alphabetic material, the magnitude of the right-field superiority was larger in right-handed males than in right-handed females (Bradshaw et al., 1977; Ehrlichman, 1971; Hannay & Malone, 1976; Levy & Reid, 1976, Marshall & Holmes, 1974). Nonverbal material presented tachistoscopically showed parallel sex effects, i.e., stronger left-field advantages in men than in women for the perception of unfamiliar faces (Berlucchi et al., 1976; Peréz et al., 1976; Umiltà et al., 1976), and for the detection, localization or enumeration of scattered dots (Davidoff, 1976; Kimura, 1969; Levy & Reid, 1976; McGlone & Davidson, 1973). Two tachistoscopic studies that have specifically examined differences in field effects according to sex, but have failed to find any, were also unable to replicate an overall left-field advantage for the perception of dot material (Bryden, 1976; Ehrlichman, 1971).

When taken together, the recent tachistoscopic findings strongly suggest that the differentiation of the left and right hemisphere with respect to verbal and nonverbal functions, is more marked in adult right-handed males than in their female counterparts. The most convincing demonstration of this was provided by Levy & Reid (1976) who found a left-visual field superiority for dot enumeration and a right-visual field superiority for letter perception in the same group of right-handers, with males consistently showing stronger laterality effects than females on both tasks.

Limitations of dichotic and tachistoscopic studies

Both dichotic and tachistoscopic studies are important sources of data on lateralization in normal subjects, but each technique is limited compared to clinical research on brain damaged patients. This applies both with respect to inferences about the functioning of one hemisphere independent of the other, and with respect to uncovering regional specialization within each hemisphere.

Dichotic studies have been less numerous, less well controlled and more contradictory than tachistoscopic studies indicating sex differences in asymmetrical brain representation. Moreover an alternative explanation of sex by laterality interactions on dichotic tasks should be considered based on peripheral rather than central auditory asymmetries.

In a review of five large-scale hearing surveys, Kannan & Lipscomb (1974) compared the median hearing thresholds for the left and right ears in middle and high frequency bands. Six of the 57 comparisons showed no significant threshold differences between ears. However, in 38 comparisons, the right ear threshold was lower than the left; thirty of these comparisons involved male samples, 8 involved female samples. In contrast, lower left-ear thresholds were reported in 13 comparisons, 4 of which involved males, and 9 involved females. This sex by ear superiority interaction is highly significant ($\chi^2 = 10.1$, $p<.005$), suggesting that auditory thresholds more often may be lower on the right than the left side in male groups, but no obvious female bias exists. Thus, if similar sex effects were present for dichotically presented verbal stimuli, they would enhance the right-ear scores in men, but not in women.

However, Cullen et al. (1974) reported that the right-ear effect for speech stimuli presented dichotically could survive up to a 20 decibel difference between ears. Since the magnitude of the ear superiority for pure tones in the preceding study was no larger than 4 decibels, one cannot dismiss sex-dependent dichotic asymmetries reported by Harshman et al. (1976) and by Lake & Bryden (1976) as reflecting merely peripheral asymmetries. Nevertheless, without audiometric screening or control nonverbal dichotic stimuli, interpretation of a larger right-ear advantage in males than in females as reflecting solely the asymmetrical cerebral representation of speech functions is not justified either.

Electrophysiological studies

To date, the few electrophysiological studies looking at degree of lateralized brain activation during verbal and nonverbal tasks are inconsistent regarding which, if either, sex may be the more asymmetrically organized.

Evoked potential recording over the temporal region in adults yielded no obvious sex differences in the specialized response of the left hemisphere to verbal stimuli presented auditorily (Molfese, 1976). Nor were there significant sex differences in amount of alpha activity between the left and right sides at temporal, parietal or occipital sites during vocabulary or visuospatial tasks (Tucker, 1976).

However, ratio or difference scores in alpha wave activity between the left- and right-hemispheres during "verbal" versus "nonverbal" tasks have been related to the sex of the subject. Davidson et al. (1976) claimed greater asymmetry in hemispheric activation (i.e., alpha dyssynchrony) in females, in contrast to Ray et al. (1976) and Tucker (1976) who claimed greater hemispheric asymmetry in males.

Limitations of EEG studies

Thus far, sex-related EEG asymmetries have been found only in ratio or difference measures between the left and right hemispheres, when these measures were compared during "verbal" and "nonverbal" tasks. However, these results tell us little about which hemisphere or even which task may have been responsible for the sex effects.

Inconsistencies in sex effects among the studies may be due to the use of different types of "verbal" and/or "nonverbal" tasks, to differences in the modality of presentation (auditory versus visual), to differences in task demands (overt versus covert), or simply to different electrode placement sites. At present, there is no way to decide which EEG study may be most accurate in its conclusions since so many of these variables were uncontrolled.

Another factor which may operate is that EEG recordings may be reflecting the degree to which there is asymmetrical control of body movements. Although investigators are aware of and eliminate artifactual EEG recordings associated with gross body movements, more subtle limb, eye and tongue movements have not been monitored. Males and females may, however, differ in amount and direction of task-related movement (see Gur & Gur, 1974; Weitan & Etaugh, 1973). Thus, EEG asymmetries that differ between males and females may be reflecting asymmetrical cerebral control of movement rather than the cerebral lateralization of verbal and nonverbal functions per se. This would be an important distinction to make, even though the underlying mechanisms controlling movement and cognitive functions may be subserved by the same hemisphere.

Anatomical studies

Anatomical asymmetries in regions of the brain believed to subserve auditory speech functions appear to be more consistent in adult males than in adult females. The planum temporale, situated posteriorly on the superior surface of the temporal lobe, is larger on the left than on the right in the majority of both sexes, a finding which has been postulated as an anatomical basis for the lateralization of language functions in the left hemisphere (Geschwind & Levitsky, 1968; Teszner et al., 1972; Wada et al., 1975; Witelson & Pallie, 1973; Yeni-Komshian & Benson, 1976). However, significantly more female than male specimens showed the reverse asymmetry pattern, with a larger right than left planum temporale (Wada et al., 1975). Although asymmetries in other speech zones, such as the frontal and parietal opercular regions, are equal in degree for both sexes (Hochberg & LeMay, 1975; Wada et al., 1975), the shape of the Sylvian fissure, which borders these speech zones, may differ between men and women. Rubens et al. (1975) judged that slightly more female (4/8) than male brains (5/16) showed symmetrical configurations of the Sylvian fissure (right-handers, only).

Investigators looking at morphological asymmetries in regions of the brain subserving visual functions have not generally examined for sex differences (Akesson et al., 1975; McRae et al., 1968). Recently, however, Wada (1976) reported sex-dependent anatomical asymmetries in the medial aspects of the occipital lobe, i.e., the cuneus. In a preliminary analysis of 24 specimens, females tended to have larger right than left cuneate areas, whereas in males the left side was larger, but these results were not statistically analyzed.

Limitations of anatomical studies

The assumption underlying these studies seems to be that hemispheric specialization may arise when one functionally distinct region of the brain contains more neurons than its contralateral homologue. However, left-right comparisons in area or gyral length have systematically excluded cortical tissue lying in the sulci. Thus, until we know that asymmetries in surface measurements accurately predict asymmetries in total numbers of neurons in a region, the pertinence of such measures is questionable.

Furthermore, it is still an open question, whether morphological characteristics form the basis of subsequent functional specialization in the brain. No study has yet demonstrated a relationship between degree or direction of anatomical asymmetry and degree of asymmetry for speech or nonspeech functions. Not all speech zones show the left-hemisphere advantage predicted on the basis of functional specialization. It is puzzling, for instance, why the frontal operculum, traditionally defined as expressive speech zone (see Penfield & Roberts, 1959), appears larger on the right. Moreover, morphological asymmetries in the temporal lobe region, similar in direction to those reported in humans, have recently been found in primate brains, i.e., in species for whom no apparent natural language has developed (LeMay & Geschwind, 1975; Yeni-Komshian & Benson, 1976). These inconsistencies suggest that anatomical asymmetries may not, in fact, be as systematically related to functional specialization of the hemispheres as initially believed.

Sex differences in anatomical asymmetries are nevertheless interesting in their own right and may be pertinent to previously reported asymmetries in EEG recordings. If the male brain is, in fact, anatomically more asymmetrical than the female brain, the probability of recording over non-homologous areas from the two sides would be greater in males than in females. Thus, whether EEG asymmetries are anatomically and/or functionally based will remain unclear until more is known about the relationship between anatomical and functional asymmetries.

Vascular asymmetries

If sex differences were present premorbidly in the vascular system, or if there were systematic biases in the localization of vascular pathology which also varied according to sex, then differences in functional asymmetry between males and females might be related more to extracerebral factors than to neural organization. This would be an important distinction to make.

Asymmetries in the arterial tree supplying blood to the brain are common. For example, the left common carotid artery arises directly off the aortic arch, whereas the right common carotid artery arises from the bifurcation of the subclavian and the brachiocephalic arteries (Truex & Carpenter, 1969). However, little information is available regarding possible left-right differences in the structure or territories of the three major arteries feeding each cerebral hemisphere, i.e., the anterior, middle and posterior cerebral arteries. It is known that the middle cerebral artery leaves the Sylvian fissure at a wider angle on the right than on the left side, but this asymmetry was equally marked in males and females (Hochberg & LeMay, 1975; LeMay and Culebras, 1972). Studies of ophthalmic artery pressure and regional cerebral blood flow suggest that there may be vascular correlates of cerebral dominance for hand preference (Carmon

& Gombos, 1970) or speech and nonspeech functions (Risberg et al., 1975), but the data have not been analyzed for difference between sexes.

Variations in the relative diameter of the three major veins draining blood from the convexity of each cerebral hemisphere may also be related to speech lateralization. The vein of Labbé usually has the largest diameter of the three on the left side, where speech functions are normally represented, but the vein of Trolard is usually the largest on the right side (Dichiro, 1972; Hochberg & Le May, 1975). Dichiro (1962), however, reported that Labbé was largest on the right in 66% of patients with right-hemisphere dominance for speech functions, as determined via speech disorders produced by sodium amytal injections (Wada & Rasmussen, 1960). Thus, the vein of Labbé appears to be the largest of the three major veins in the hemisphere subserving speech functions. These asymmetries were of the same magnitude in men and women (Hochberg & Le May, 1975; Matsubara, 1960).

Cerebro-vascular disease, however, often occurs asymmetrically and may differ between males and females in type, site and side. According to Hutchinson & Acheson (1975), there is no general consensus regarding differential morbidity and mortality rates between male and female subjects with cerebro-vascular diseases. One epidemiological study by Kurtzke (1969) suggested that cerebro-vascular diseases, if undifferentiated by etiology, occurred equally often in males and females, but if further differentiated, vascular diseases of atherosclerotic origins, i.e., abnormal growth and hardening of the vessel walls, were more common in males than in females. Cerebro-vascular insults due to aneurysm, i.e., weakening and ballooning of the vessel wall, or vascular disease due to vessel blockage by embolic material occurred more often in females than in males (Kurtzke, 1969).

In general, arteries feeding the left side of the brain are occluded more often than those on the right side, although this trend is not significant in every investigation and may further depend upon the particular artery being studied (Hutchinson & Acheson, 1975; Kaste & Waltimo, 1976; Sindermann et al., 1969; 1970). Data from at least three independent surveys suggest that the preponderance of left-sided vascular lesions was equal in magnitude across male and female samples (Hutchinson & Acheson, 1975; Kaste & Waltimo, 1976; Sindermann et al., 1970). However sex differences were found in patients with recurrent vascular episodes whereby the side of first episode was significantly more often the left in males, but the right in females (Hutchinson & Acheson, 1975).

Within a hemisphere, the most frequently occluded cerebral arteries are the internal carotid artery, the trunk of the middle cerebral artery, and one or more branches of the middle cerebral artery (Carter & Brain, 1964). The site of occlusion within these vessels appears to differ between the sexes, with males tending toward occlusions in the proximal vessels, whereas females tend more toward occlusions in the distal vessels. Thus, significantly more males than females suffered occlusions in the internal carotid artery than in the middle cerebral artery (Sindermann et al., 1970), and significantly more males than females suffered occlusions in the trunk of the middle cerebral artery than in one or more of its branches (Kaste & Waltimo, 1976). However, sex differences in the site of middle cerebral artery occlusion, when further analyzed by side, were significant only on the left, not on the right side (Kaste & Waltimo, 1976).

If it can be argued that occlusions in the distal portion of an artery results in less ischemic damage (i.e., tissue damage due to an inadequate blood supply) than more proximally occurring occlusions, then female stroke patients should demonstrate less extensive ischemic damage than males, particularly on the left side. If this were true, it might follow that neurological and psychological deficits subsequent to left-hemisphere ischemic damage may also be less marked in females than in males.

However, occlusion of a vessel does not necessarily result in ischemic damage to all brain tissue in the territory beyond the site of blockage because of collateral circulation (Vander Eeken, 1959). The major cerebral arteries are linked to each other via anastomotic connections at the base of the brain (the Circle of Willis) and on the cortical surface. When a change in blood pressure occurs, anastomotic circulation allows blood to flow from healthy vessels into the territory of an occluded vessel, thus preventing some ischemic damage. It is, therefore, not surprising that the type, severity and recovery of neurological deficits such as hemiparesis, visual field defects, and aphasia, are not systematically related to site or degree of the occlusion in any particular artery (Dyken et al., 1974; Sindermann et al., 1969; Waltimo et al., 1976; Yarnell et al., 1976).

In summary, very little is known of sex differences in the blood supply to the left and right hemispheres, either in health or in disease. The available data suggest that males and females may differ in site of occlusion within a vessel (distal versus proximal), particularly on the left side. However, no clear relationship has been demonstrated between site of occlusion and type or extent of neurological deficit. Nor is it known whether spontaneous collateral filling of occluded vessels occurs more often on one side of the brain than on the other, or in one sex more often than in the other.

Developmental studies

Studies concerned with differences between men and women in degree of functional brain asymmetry thus far provide very little support for, and much evidence against Buffery & Gray's

(1972) position that female brains may be more asymmetrically organized than male brains. However; Buffery & Gray's conclusions were based upon data collected in children rather than adults. Therefore, the effect of age and sex on hemispheric specialization will be reviewed here to assess the apparent discrepancies between the adult and children's literature.

Verbal functions

Few clinical studies have examined the effects of strictly unilateral brain lesions in childhood, and even fewer report the data separately for girls and boys. A preliminary analysis based on a small sample of seven year-old children, whose lesions dated from the first year of life, yielded no statistically significant laterality effects or sex by laterality interactions on verbal intelligence, reading or spelling (Lansdell, 1976). However, locus and extent of perinatal brain injury were not controlled across girls and boys, precluding any definitive statement regarding the effects of sex on lateralized brain lesions in children.

There appears to be some controversy in the dichotic literature with respect to the effects of sex on degree of speech lateralization in right-handed children. Kimura (1967) tested 5 to 8 year-old children from a lower socio-economic area and found a significant right-ear effect in each group except in 5 year-old boys. Seven to 11 year-old girls with reading disabilities (dyslexia) showed significant right-ear effects for verbal material, but dyslexic boys of the same age did not (Taylor, 1962). From these two studies, Buffery & Gray (1972) concluded that left-hemisphere speech lateralization occurred earlier in females than in males, and this sex difference was merely accentuated in children with reading difficulties.

The association of dyslexia with attenuated right-ear effects specifically in boys, however, has been partially contradicted recently by Witelson (1977). In her sample, 85 dyslexic and 156 nondyslexic boys, ranging from 6 to 14 years of age, showed equally significant right-ear effects for the lateralized perception of digits. Buffery and Gray's conclusions are also inconsistent with more recent dichotic studies in children younger than 5 years of age, which have yielded significant right-ear effects in both sexes as early as age three (Ingram, 1975a; Nagafuchi, 1970).

Table 1 contains a systematic review of six dichotic studies in 3 to 9 year-old right-handed, nondyslexic children. These studies were selected because at each age tested the statistical significance of the right-ear effect was calculated separately for each sex. Over all the age by sex comparisons, significant right-ear effects appeared more often in boys than in girls ($\chi^2 = 3.6$, $p < .07$). This trend was strongest in 4 year-olds, but

TABLE 1

The Incidence of a Significant Right-Ear Superiority on Verbal Dichotic Listening Tasks as a Function of Age and Sex

STUDY / AGE	3 Boys	3 Girls	4 Boys	4 Girls	5 Boys	5 Girls	6 Boys	6 Girls	7 Boys	7 Girls	8 Boys	8 Girls	9 Boys	9 Girls
Nagafuchi (1970) - 2 syllables	**	-	-	-	**	-	**	-						
Nagafuchi (1970) - 3 syllables	**	**	**	-	-	**	**	-						
Ingram (1975a) - digits	**	**	**	-	**	**								
Kimura (1963b) - digits			**	**	**	**	**	**	**	-	**	**	**	-
Kimura (1967) - digits					-	**	**	**	**	**	**	**		
Geffner et al. (1976) - syllables			**	-										
Pizzamiglio & Checchini (1971) - words					-	**								

** = significant right-ear superiority
- = right-ear superiority not statistically significant at the $p < .05$ level

reversed in the 5 year-olds. Though not exhaustive, Table 1 suggests that degree of left-hemisphere speech representation, as measured by a significant right-ear effect, may be greater in boys than in girls at some age levels. Consistent with this conclusion, Bryden (1970) reported that the proportion of right-handers with higher right-ear scores increased from grade 2 to grade 6 in boys, but decreased in girls.

In Table 1, only 4 studies fail to show a significant right-ear advantage in boys. The fact that 3 of these exceptions occurred in 5 year-old children suggests that Kimura's (1967) original findings were not pure chance. It is unlikely that her results were attributable to low socioeconomic levels, since other investigators have not found significant interactions of socioeconomic level, sex and the right-ear effect (Borowy et al., 1976; Geffner & Dorman, 1976; Geffner & Hochberg, 1971). Apparent fluctuations in the right-ear effect may instead be related to periods of cerebral reorganization, but this idea is only speculative at present (Ingram, 1975a).

Even if Kimura's data were age-specific, there are two major factors which may systematically act to enhance right-ear effects in boys relative to girls. First, peripheral hearing thresholds, which tend to be lower on the right side only in males (Kannan & Lipscomb, 1974), may contribute to the more frequent occurrence of statistically significant right-ear effects in boys, compared to nonsignificant trends in girls. Secondly, as overall performance in dichotic tasks improves, the right-ear effect measured by the right minus left ear score, diminishes (Harshman & Krashen, 1972). A female superiority in verbal memory (see Maccoby & Jacklin, 1974) has been found in the recall of digits presented dichotically (Borowy et al., 1976; Kimura, 1963b). Thus, attenuated right-ear effects in females may partially be related to higher overall accuracy scores, though this seemed not to be the case in Borowy et al. (1976) or Kimura (1963b).

The right-ear effect has been closely associated with rate of sexual maturation during puberty, whereby early maturers show a less marked right-ear advantage than late maturers (Waber, 1976; 1977). This finding raises the interesting possibility that the less marked right-ear effect found more often in girls than in boys may be linked to the former's generally advanced physical and/or sexual maturation rates compared to males (Taylor & Ounsted, 1972). Indeed, when boys and girls were matched for rate of sexual maturation, rather than for chronological age, no sex differences in right-ear effects were found in the early adolescent years (Waber, 1976; 1977).

Other dichotic listening studies examining the effects of age and sex on right-ear superiority for verbal material have not provided enough detailed information to be included in Table 1. The majority, however, reported no significant interactions of sex with ear superiority (Berlin et al., 1973; Borowy et al., 1976; Geffner & Hochberg, 1971; Knox & Kimura, 1970; Satz et al., 1975).

Tachistoscopic procedures employing alphabetical material to determine degree of speech lateralization are precluded in very young children who lack the necessary reading skills. Presumably, pre-readers identify letter material through visual-visual matching, rather than visual-phonetic matching. Furthermore, the degree to which letter symbols are treated as "verbal" material, i.e., matched to a phonetic code, affects the direction and degree of right-visual field effect (Cohen, 1972; Geffen et al., 1972). Thus, tachistoscopic word recognition is influenced by reading proficiency, which, in turn, is generally advanced in girls compared to boys (for review, see Maccoby & Jacklin, 1974). When boys and girls are matched for chronological age and have average or above average reading skills, tachistoscopic studies of verbal asymmetries in right-handers have failed to show significant effects of sex on right-field superiority (Marcel & Rajan, 1975; Yeni-Komshian et al., 1975). One study, however, found that the right-field advantage was significantly greater in boys than in girls (Marcel et al., 1974), although longer exposure times for males than females may have influenced these results.

Anatomical asymmetries in infants have been studied by Wada et al. (1975) who reported sex effects contradictory to those found by Witelson & Pallie (1973). The latter investigators, with a sample of only 5 infant brains of each sex, claimed that the increased size of the planum temporale on the left was significant in female, but not in male specimens. However, in Wada's series of 89 infant brains, left-right differences in the planum temporale were greater in males than in females, though not significantly so (Wada et al., 1975). Asymmetries in the frontal operculum did not differ significantly between sexes in the infant series, though there was a trend for a higher proportion of the females to show reversed asymmetry patterns (Wada et al., 1975).

Nonverbal functions

Very few investigators have examined sex influences on auditory or visual, nonverbal asymmetries in children. Those few who have, found no significant effects (Knox & Kimura, 1970; Lansdell, 1976; Marcel & Rajan, 1975; Wada, 1976).

However asymmetries in tactual and tactual-spatial functions differ between boys and girls. A left-hand superiority has been reported for single point pressure sensitivity (Ghent, 1961; Kimura, 1963b), for the identification of unfamiliar shapes (Witelson, 1976) and for Braille letter learning (Rudel et al., 1974). On thumb sensitivity, girls showed the laterality effect at an earlier age than boys, in contrast to tactual shape recognition and Braille learning where boys showed a left-hand superiority before girls.

The left-hand advantage on haptic shape identification and Braille learning, which appeared in boys as young as six, but in girls not until puberty, may reflect a male advantage in right-hemisphere control of tactile-spatial functions (Rudel et al., 1974; Witelson, 1976). However, a less marked left-hand superiority in girls may also be related to greater left-hemisphere participation in the task via verbal mediation or via superior right-hand motor control.

If girls tended to identify shapes or dot configurations verbally -- a likely bias given their superior language skills -- this might reduce the left-hand (i.e., right-hemisphere) advantage. Similarly, the left hemisphere's control over the right limb, which tends to be more marked in girls than in boys (see next section) may reduce the right-hemisphere's influence in those tactual spatial tasks which involve movement.

Little in the way of verbal mediation or limb movement is required in the determination of single point pressure sensitivity thresholds, and it is interesting that on this task a left-hand advantage emerges earlier in girls than in boys (Ghent, 1961; Kimura, 1963b). However, the underlying neural basis of this asymmetry is unclear. It could arise either from superior contralateral control by the right hemisphere or, paradoxically, from a greater amount of ipsilateral representation in the left hemisphere (Semmes et al., 1960). Semmes (1968) has argued that the left hemisphere has greater ipsilateral representation of certain sensory and motor skills than does the right hemisphere. An explanation of sex-related pressure sensitivity asymmetries on the basis of increased ipsilateral control would help to account for the apparently contradictory sex effects on the various tactual tasks (Ghent, 1961; Rudel et al., 1974; Witelson, 1976), and would be in keeping with other findings suggesting advanced left-hemisphere control of certain motor functions in females compared to males (see next section). Hence, many of the apparent tactile asymmetries in the female may be explicable by a single asymmetrical representation -- that of left-hemisphere control -- speculation which is not necessarily contradictory to the suggestion of greater right-hemisphere control of tactile spatial functions in boys than in girls.

Nonverbal motor functions

Most children prefer the right hand for writing and other skilled motor acts, but there are more right-handed girls than boys (Annett, 1970; Jones, 1947). Moreover, among right-handers, girls show more consistent preferences for the right side, and more superiority for right-hand strength and dexterity than do males (Annett, 1970; Buffery & Gray, 1972; Denckla, 1973; Ingram, 1975b; Jones, 1947). These findings, which also hold true in adult populations, suggest that the neural control of motor systems involved in limb preference may be more asymmetrically organized in females than in males (Annett, 1973; Heim & Watts, 1976; Hicks & Kinsbourne, 1976; Oldfield, 1971; Newcombe et al., 1975; Thompson & Marsh, 1976).

Since movement on one side of the body is primarily controlled by the contralateral hemisphere, it follows that a more marked right-hand preference in females may be indicative of greater left-hemisphere control. This prediction is compatible with Conel's (1963) observation of sex differences in rate of maturation between the left and the right hemisphere as measured by degree of myelination. The fibre pathways of the left face and hand areas were better developed in four year-old girls (4 specimens) than in boys of the same age (3 specimens), but the same pathways on the right side were better developed in boys than girls (Conel, 1963).

Thus, motor functions differ from other asymmetrically organized functions, in that females appear to be more asymmetrically organized than are males, particularly with respect to left-hemisphere control.

General conclusions

Thus far, the topic of hemispheric specialization as a function of sex has been inadequately studied, with most findings appearing haphazardly in the literature. In general there is more agreement than disagreement between developmental and adult samples. The currently available data from normal studies favour less hemispheric specialization for verbal functions in females than in males. In males, verbal functions are apparently more dependent on the left hemisphere than is the case in females. For motor skills, however just the opposite sex effects appear to operate, with females more asymmetrically organized than males. In contrast, visuospatial functions as studied by tachistoscopic procedures appear to be under greater right-hemisphere control in adult male right-handers than in females. Much less is known of nonverbal functions in the auditory or tactile modalities.

The most convincing evidence that male and female brains differ in degree of hemispheric specialization thus comes, not from clinical studies of brain damaged patients, but from very recent normative research. The clinical studies have been disappointing in that they have usually failed to match sex and hemisphere groups on factors which effect degree of brain lateralization and/or cognitive ability. Nevertheless, the trends in those studies, as well, is for greater asymmetrical representation of both spatial and verbal functions in males.

The current study

In an attempt to resolve some of the contradictory findings in the clinical literature, the present investigation examined the effects of unilateral brain damage separately in men and women to determine whether or not there are meaningful sex differences in the lateralized representation of verbal and non-verbal functions. To conclude that differences between male and female groups were related to sex differences in brain organization, it was necessary to insure that extraneous factors known to affect performance on psychological tests were comparable across sex and laterality groups. Thus, patient groups were equated, as far as possible, for age, education, hand preference, extent, locus and etiology of the brain lesion, length of illness, and familial sinistrality.

In the first paper, results of standardized Verbal and Performance Intelligence scores are compared between male and female patients with left- or right-hemisphere damage. The second study focused on the cerebral lateralization of verbal functions. A variety of language-related tasks were administered to men and women with left- or right-hemisphere lesions, and to a control group of healthy subjects, with a view to comparing the sexes on severity and type of language disorder after unilateral brain lesions.

PAPER I

SEX DIFFERENCES IN FUNCTIONAL BRAIN ASYMMETRY

Cortex, in press.

ABSTRACT - PAPER I

Adult male right-handers showed the expected pattern of verbal intellectual decline following left-hemisphere lesions, and depressed nonverbal intelligence following right-hemisphere lesions. In contrast, right-handed women did not show selective verbal or performance intellectual deficits after unilateral brain injury. These findings suggest a greater degree of functional brain asymmetry in right-handed men than women.

INTRODUCTION

In adult right-handers, damage to the left hemisphere of the brain is reported to disrupt language functions, whereas damage to the right hemisphere primarily affects nonverbal, visuospatial skills (for review see Mountcastle, 1962). Thus, the term, "functional brain asymmetry" implies that the left hemisphere is specialized for verbal processes and that the right hemisphere is specialized for nonverbal functions (Kimura, 1973). According to a substantial body of literature these same lateralized functions are performed with differing degrees of ability by males and females. For example, females show superior verbal ability on word fluency and articulation measures, whereas males usually demonstrate superior spatial ability (Maccoby & Jacklin, 1974). The fact that males and females differ in their performance of these functions raises the possibility that cerebral lateralization itself may differ according to sex.

Only in the last sixteen years has the relation of sexual phenotype to functional brain asymmetry been examined. Lansdell (1961; 1962; 1968) first reported that the nature of the cognitive deficit seen after unilateral temporal lobectomy depended not only on the side of the excision, but also on the sex of the patient. Later studies by Kimura (1969) and McGlone et al. (1973a; 1973b) indicated that men showed a greater degree of right-hemisphere specialization for spatial functions than did women. However, little is known about sex differences in the cerebral representation of verbal abilities.

METHOD

This study examined both verbal and nonverbal intellectual abilities following left- or right-hemisphere lesions in males and compared them with females. Patients 15 to 70 years of age whose initial injury occurred after age 10 were tested. The sample consisted of 85 right-handers with unilateral brain injury admitted to the Neurology or Rehabilitation wards of the University Hospital in London, Ontario from 1973 to 1975. Severe language disorders in 8 aphasics (6 men and 2 women with left-hemisphere damage) precluded intellectual assessment. Thus, the data will be reported for 23 men and 20 women with left-hemisphere lesions, and 17 men and 17 women with right-hemisphere lesions. Localization of the lesion was based upon lateralizing signs reported in any of the following: neurological examination, brain scan, angiogram, electroencephalogram and/or operative note. No patient showed evidence of bilateral cerebral pathology and none had psychiatric histories. Vascular accidents (completed stroke or aneurysms) accounted for two-thirds of the sample, and the remaining third were diagnosed as tumor. Patients with transient ischemic attacks, arteriovenous malformations, seizures and closed head injuries were excluded because of the small N's in each group and the difficulties establishing duration and/or extent of brain injury.

The Wechsler Adult Intelligence Scale (1955) was administered individually to each patient while in hospital. Calculation of the Verbal Intelligence Quotient (IQ) included all six subtests (Information, Comprehension, Similarities, Arithmetic, Digit Span and Vocabulary). However, Performance IQ was pro-rated on the basis of the following 4 subtests: Picture Completion, Block Design, Picture Arrangement, and Object Assembly. It was decided to exclude Digit Symbol from the Performance IQ of all patients because right hemiparetics were awkward in manipulating a pencil on this timed writing task. The patient groups were well matched on several variables believed to affect intelligence scores (Matarazzo, 1972). No significant differences appeared between males and females with left or right hemisphere lesions in: age ($\bar{X}$ = 48.5 years); education ($\bar{X}$ = 11.1 years); or length of illness (vascular $\bar{X}$ = 4.5 months; tumor $\bar{X}$ = 32.7 months). Visual field defects and hemiparesis were similarly controlled across groups.

An analysis of variance for unequal N's was performed on the intelligence scores diagrammed in Fig. 1. The four factors were: Side of Lesion (left, right), Sex (male, female), Etiology (vascular, tumor) and Task (Verbal IQ, Performance IQ). Since sex differences in perceptual deficits were predicted on an a priori basis, the significant Side by Sex by Task interaction (F = 7.44, 1,69 df, $p < .01$) was further examined via two-tailed t-tests. The .01 probability level was chosen as a conservative indication of

Figure I

WAIS Verbal and Performance mean IQ scores in male and female patients with left or right brain injury.

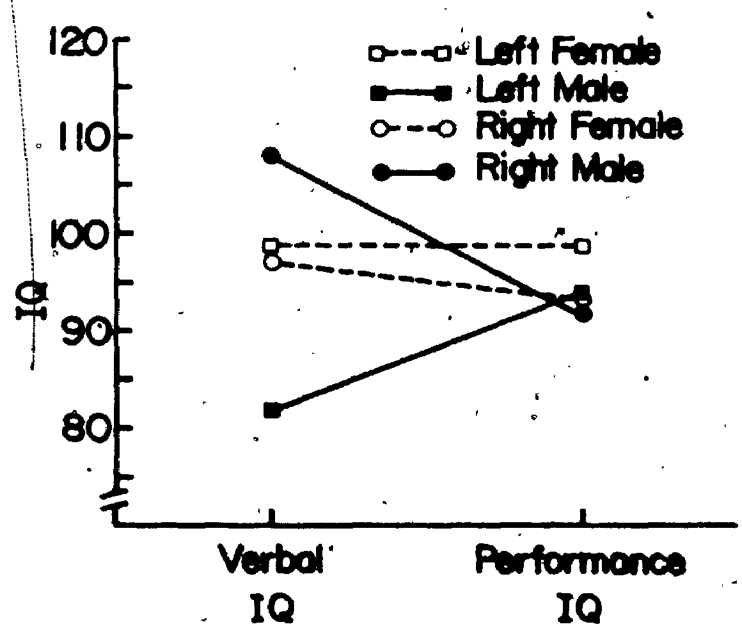
Left Female
Left Male
Right Female
Right Male
120
110
100
90
80
IQ
Verbal IQ
Performance IQ

FIGURE I

significant differences between means.

RESULTS

Verbal IQ. Men with left-sided lesions obtained lower Verbal IQ scores than all other groups. Figure I shows that left-damaged males ($\bar{X}$ = 83.1) were significantly worse than men with right-sided lesions ($\bar{X}$ = 106.8; t = 3.08, 39 df, p<.01); lower than women with right-sided lesions ($\bar{X}$ = 98.9; t = 2.03, 39 df, p<.05); and lower than women with left-sided lesions ($\bar{X}$ = 99.1, t = 2.26, 46 df, p<.05). In contrast, women with left-sided lesions obtained a mean Verbal IQ (99.1) well within the Average range [i.e., 90 to 109 according to Wechsler's norms (1955)], and their scores did not differ from either women with right-sided damage (t = 0.05, ns) or men with right-sided damage (t = 1.99 ns). Thus, Verbal IQ deficits appeared only in men with left-hemisphere lesions, findings which imply more asymmetrical, left-hemisphere control of such verbal abilities in men compared to women.

As mentioned previously, 6 men and 2 women are untestable on intellectual measures because of severe language difficulties. In the remaining 43 testable patients with left-hemisphere damage, aphasic disorders were 3.7 times more common in the male sample than in the female sample (for aphasia criterion see McGlone, 1976). Thus, it would appear that the lower Verbal IQ scores in left-damaged males may be reducible to a preponderance of aphasic males compared to aphasic females. However, the sex-dependent impairments in Verbal IQ remained significant even when all aphasics were later eliminated from the statistical analyses (McGlone, 1976). These results suggest that men more often than women were rendered aphasic by a left-hemisphere lesion, but among non-aphasics with left-brain damage, men continued to show significantly greater Verbal IQ deficits than women (McGlone, 1976).

Performance IQ. The Performance IQ scores did not differ significantly according to sex or laterality of the lesion. Figure I shows that males with left-hemisphere lesions obtained a Performance IQ of 94.3; males with right-hemisphere lesions scored 93.3; females with left-hemisphere lesions scored 99.2; and females with right-hemisphere lesions scored 94.7. Including the Digit Symbol subtest scores in the calculation of Performance IQ did not alter the results in any way.

Verbal-Performance Discrepancy. Within a single patient, one can measure nonverbal functions relative to language functions by taking a difference score between the Performance IQ and Verbal IQ. Fig. IIA depicts the mean discrepancy scores in graph form for each patient group. A positive value indicates higher Verbal IQ than Performance IQ, and a negative value indicates the reverse relationship.

Only men showed the expected pattern of significant Verbal or Performance IQ deficits depending upon the laterality of the

Figure II

WAIS Verbal minus Performance IQ discrepancy scores for male (black columns) and female (striped columns) patients with left or right brain damage. A - Combined etiological groups. B - Vascular groups. C - Tumor groups.

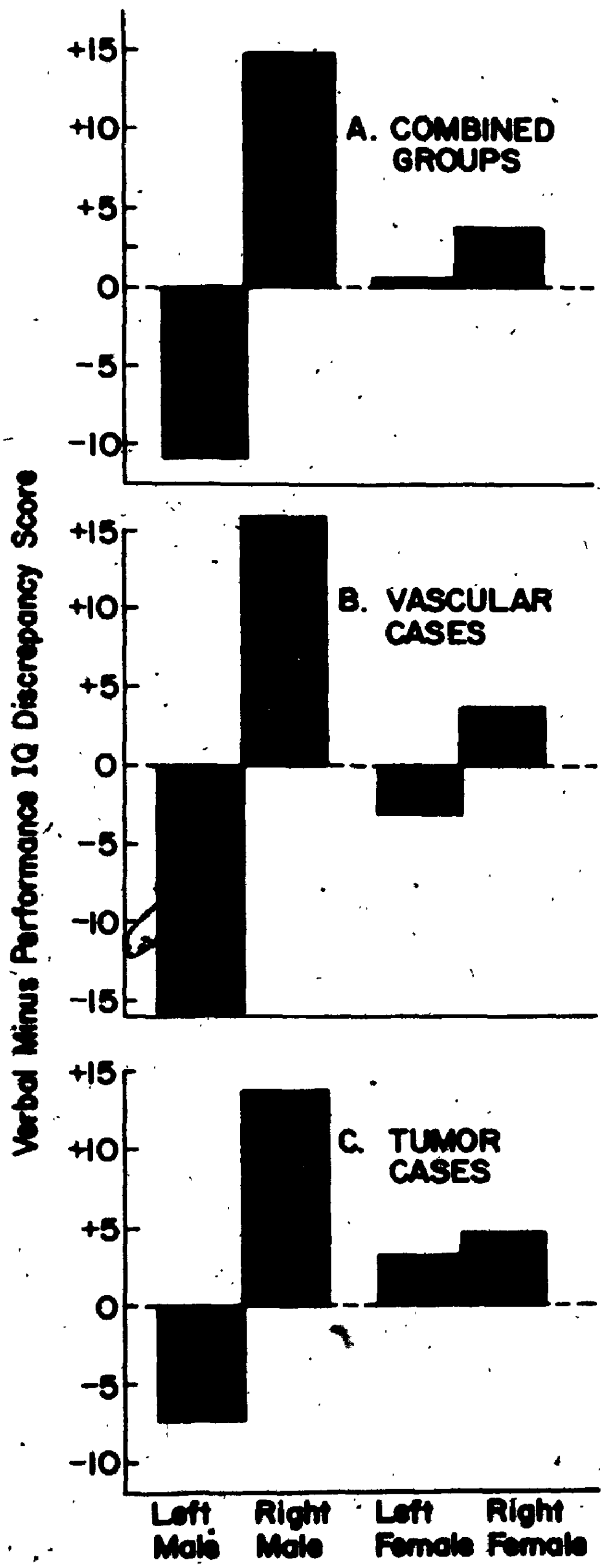
Verbal Minus Performance IQ Discrepancy Score
+15
+10
+5
0
-5
-10
A. COMBINED GROUPS
+15
+10
+5
0
-5
-10
-15
B. VASCULAR CASES
+15
+10
+5
0
-5
-10
C. TUMOR CASES
Left Male
Right Male
Left Female
Right Female

FIGURE II

lesions: that is, in men, left-hemisphere damage impaired Verbal IQ much more than Performance IQ ($t = 4.85$, 22 df, $p < .001$), and right-hemisphere damage lowered Performance IQ compared to Verbal IQ ($t = 3.43$, 16 df, $p < .01$). In women, Verbal and Performance IQ measures were not significantly different, whether the lesion was on the left ($t = 0.26$, ns) or on the right ($t = 1.04$, ns). These sex differences in the pattern of cognitive deficits related to unilateral cerebral injury suggest that the adult male brain is more asymmetrically organized than the female brain, for both verbal and nonverbal abilities. It is important to emphasize here that etiological factors did not markedly alter the results (see Fig. IIB for vascular cases and IIC for tumor cases). Therefore, the findings reflect differences in underlying brain function rather than peculiarities in source of pathology or differing cerebral circulations.

DISCUSSION

This study clearly demonstrates that the pattern of deficits seen after unilateral brain lesions depends to a considerable extent on the sex of the patient as well as on the side of the lesion. Only men in the sample showed specifically verbal IQ deficits after left-hemisphere damage or nonverbal relative to verbal IQ deficits after right-hemisphere damage. For the women, cognitive deficits tended to be less specific and less severe compared to men. The findings support the idea of greater functional brain asymmetry in adult male than female right-handers, most clearly for verbal processes, but also for nonverbal processes.

These data are consistent with earlier clinical studies that have found sex differences in the type of deficit seen after unilateral cerebral lesions (Lansdell, 1961; 1962; 1968; 1973; Lansdell & Urbach, 1965; McGlone & Kertesz, 1973). More recent dichotic listening and tachistoscopic research with non-brain damaged adult subjects would also suggest greater functional asymmetry for verbal and nonverbal processes (Hannay & Malone, 1976; Lake & Bryden, 1976; Levy & Reid, 1976; McGlone & Davidson, 1973) and greater structural asymmetry in the adult male brain than the female brain (Wada et al., 1975).

Sex-dependent hemispheric specialization has also been reported in the developing organism as well as in adults, but there is still much controversy in the children's literature regarding which sex may be more asymmetrically organized for verbal, spatial and/or sensori-motor functions (Annett, 1972; Buffery & Gray, 1972; Denckla, 1973; Ghent, 1961; Ingram, 1975; Kimura, 1967; Marcel et al., 1974; Witelson, 1976). There could be several explanations for the lack of consistency in the developmental literature, the first of which is difficulty obtaining reliable and valid measures of brain asymmetry in young children using dichotic listening and tachistoscopic techniques. Secondly, there may, in fact, be differences between girls and boys in rate of brain maturation (Conel, 1963; Goldman et al., 1974; Taylor, 1969). Furthermore, verbal, spatial and sensori-motor systems may develop at differing rates with respect to each other as well as with respect to each sex. Rate of sexual maturation at puberty affects verbal and spatial skills, and is also related to degree of speech lateralization (Waber, 1976). Thus it is possible that rate of neural, physical and or sexual maturation, which differs between the sexes, may be related in a complicated fashion to hemispheric specialization before and after puberty, as well as during the early adolescent years. The present study, however, strongly suggests that in adulthood, functional brain asymmetry is more characteristic of the right-handed male population than of right-handed females.

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PAPER II

SEX DIFFERENCES IN THE CEREBRAL ORGANIZATION OF VERBAL FUNCTIONS IN PATIENTS WITH UNILATERAL BRAIN LESIONS

Submitted to Brain.

ABSTRACT - PAPER II

Sex differences in the cerebral organization of speech functions were examined by looking at the incidence and degree of aphasia, and the pattern of verbal intelligence and memory scores in 55 right-handed men and 47 right-handed women with unilateral brain damage. A striking sex difference in the incidence of aphasia revealed that three times more men than women with left-hemisphere lesions were classified as aphasic. Moreover, when aphasics were eliminated from the sample, only males continued to show the expected pattern of depressed verbal intelligence and depressed verbal memory after left-hemisphere damage compared to right-damaged males. No significant differences in these verbal scores appeared between females with left- and right-brain damage, but both female groups were significantly impaired on verbal intelligence relative to non-brain-damaged controls. There were no cases of aphasia after right-hemisphere damage.

The sex differences in verbal deficits were not explicable on the basis of age, education, etiology, length of illness, clinical signs, locus or severity of the lesion, familial sinistrality or generalized intellectual deterioration. The data were interpreted as supporting the idea that females, as a group, show a more heterogenous pattern of cerebral speech representation than do males.

INTRODUCTION

The cerebral hemispheres in man are known to be asymmetrically organized in that verbal functions are more left-hemisphere dependent whereas nonverbal functions are more right-hemisphere dependent (see reviews in Mountcastle, 1962; Milner, 1975). However, the sex composition of the original patient samples on which these conclusions were based (when sex was reported at all) was predominantly male. This bias is explicable in clinical settings where many more male than female patients suffer neurological disorders (Ounsted & Taylor, 1972), and of course, veterans' populations are exclusively male (Benson, 1967; Newcombe, 1969). Only recently have the patterns of verbal/nonverbal deficits subsequent to left- and right-hemisphere lesions been examined separately for males and females, with some unexpected findings.

To date, the clinical reports of sex differences in the effects of unilateral brain damage have consistently suggested greater functional asymmetry in the adult male brain (Lansdell & Urbach, 1965; McGlone, 1976). These findings however, have been transitory (Lansdell, 1962), unreplicable (Lansdell & Urbach, 1965; Lansdell, 1968a) or suggestive but not statistically significant (McGlone & Kertesz, 1973). Evidence that specifically nonverbal functions are more lateralized in males than in females is more convincing (Lansdell, 1962; 1968b; McGlone & Kertesz, 1973).

whereas findings regarding verbal asymmetries are conflicting (Eisenson, 1967; Lansdell, 1961; 1968b; 1973; McGlone & Kertesz, 1973).

This study was designed to investigate systematically the possibility of sex differences in the cerebral lateralization of verbal functions. Sex-related nonverbal asymmetries in the same patient population will be reported in a later publication (McGlone, in preparation). Careful selection of patients excluded those with bilateral cerebral lesions. A wide range of abilities was sampled so that both gross and subtle verbal functions could be evaluated (i.e., speech production and comprehension, verbal intelligence and memory).

PATIENTS

From an original sample of approximately 200 patients suspected of unilateral brain lesions on admission to hospital during 1973 to 1976, the data are based on 92 who satisfied the following criteria: right-hand preference; age between 15 and 70 years, with the lesion onset after age 10; vascular or neoplastic etiology; no record of bilateral brain damage on the neurological examination or any further investigations such as brain scan, EEG, angiogram, air study, computerized transaxial tomography or operation; and cooperation during testing (but not necessarily ability to complete all tests). Hand preference was determined by having patients demonstrate eight everyday activities. Seven of these, including writing, had to be performed by the right hand. In doubtful cases (some aphasics, apraxics, or hemiparetics), if reliable hand preference information was not obtained from a relative, the patient was excluded from the sample.

There were 32 men and 20 women with left-sided lesions, and 23 men and 17 women with right-sided lesions. Table I contains the age, educational level, median length of illness, incidence of familial sinistrality (i.e., left-handed sibling or parent) and etiological composition of each sex by laterality group. No significant differences were found among the four patient groups on any of these factors.

The majority of vascular patients suffered occlusion of the internal carotid and/or middle cerebral arteries, whilst the remaining vascular cases were seen after the surgical clipping of an aneurysm which had bled. The neoplastic group included 16 gliomas, 10 meningiomas, 2 metastases, and 2 abscesses.

Lateralization of the lesion was determined on the basis of positive signs reported in at least two of the following independent investigations: neurological exam, angiogram, EEG, brain scan, air study or computerized tomography. In 4 cases, only the clinical examination was available. For these 4 patients lateralization was inferred on the basis of unilateral hemiparesis in addition to either a visual field defect or sensory loss on the same side.

TABLE I

Description of Patient Sample

	(N)	Vascular Occlusion	Aneurysm or Hemorrhage	Tumor	Mean Age	Mean Education	Median Illness (Months)	% With Familial Sinistrality
Left damage: Male	(32)	22	1	9	55.1	10.1	1.0	22%
Left damage: Female	(20)	11	1	8	49.9	11.6	1.4	26%
Right damage: Male	(23)	12	1	10	46.4	11.6	3.0	26%
Right damage: Female	(17)	9	5	3	48.4	10.9	2.5	35%

Extent and locus of the tissue damage was measured indirectly via clinical signs. Table II shows that the incidence of unilateral weakness and visual field defects, alone or in combination, occurred with equal frequency in each group with one exception. There were significantly more left hemiparetics than right hemiparetics ($X^2 = 5.01$, 1 df, $p < .05$), but no interactions with sex were present on this or other measures in Table II.

Non-brain damaged volunteers from a senior citizens' club (4 men, 11 women) were also administered some tasks. They were older than the patients ($\bar{X} = 68.4$ years), with an average of 10.4 years education and a mean Full Scale IQ of 114.9 on the Wechsler Adult Intelligence Scale (Wechsler, 1955).

PROCEDURE

Patients were tested individually, and several different examiners took part in a portion of the testing as part of the clinical service in the Neuropsychology section. It was not always possible for every patient to receive all tests due to scheduling difficulties or unexpected patient discharge. In general, intellectual and memory functions were assessed in one session, with aphasia testing completed within 2 days of that evaluation.

I. Incidence of Aphasia (Minnesota Test for the Differential Diagnosis of Aphasia).

The presence of aphasia was determined on the basis of six subtests from the Minnesota Test for the Differential Diag-

TABLE II

Incidence of Visual Field Defects and Unilateral Weakness

	Visual Field Defect	Weakness	Visual Defect + and Weakness
Left damage: Male	31%	63%	22%
Left damage: Female	45%	65%	30%
Right damage: Male	41%	82%	38%
Right damage: Female	29%	88%	29%

nosis of Aphasia (Schuell, 1965). These tests involved counting to 20, saying the days of the week, naming pictures, recognizing common words, identifying items named serially and understanding sentences. Patients were classified as aphasic if they made 3 or more errors on this battery; that is, if they scored 87 or less out of a maximum possible score of 90. Testing of patients and the establishment of the cutoff score was done by independent researchers whose purpose in collecting the data was not related to sex differences (Mateer & Kimura, in press).

II. Degree of "Dysphasia"

In order to assess degree of both expressive and receptive language skill, tasks which could sample a broad range of difficulty within a short period of time were needed. Since no single published aphasia battery met both requirements, elements were borrowed from several sources (Schuell, 1965; Goodglass & Kaplan, 1972). The four "Expressive" tasks included: (1) repetition of words and short phrases; (2) naming the months; (3) naming pictures; and (4) oral fluency, which required the patients to generate as many words as possible beginning with the letter "d" in one minute. The maximum Expressive score was 86 (1 point per correct response, with a limit of 25 points maximum for oral fluency). The three "Receptive" tasks minimized speech production, requiring simple "yes-no" responses or pointing. They included: (1) sentence comprehension; (2) items taken from the Peabody Picture Vocabulary Scale - Form b (Dunn, 1965) (items 6-10, 21-25, 41-45, 61-65, 81-85, 101-105, 121-125). When E said a word, the patient pointed to the correct picture out of four alternatives; and (3) all items from the Mill Hill Vocabulary Scale - Set B (Raven, 1963). The patient pointed to the correct printed word out of four (rather than six) alternatives. Word lists were presented in a vertical array to minimize visual scanning asymmetries and lateral neglect. E read aloud the stimulus word and the printed alternatives while pointing to them each in turn, if the patient was unable to do this himself. The total Receptive score was 77 (1 point per correct response). The combined Expressive plus Receptive score was 163. The tests were sufficiently difficult that most normal persons would not get 100% correct.

III. Verbal Intelligence (Wechsler Adult Intelligence Scale - WAIS).

Calculation of the Verbal Intelligence Quotient (IQ) was based on all six subtests: Information, Comprehension, Similarities, Arithmetic, Digit Span and Vocabulary (Wechsler, 1955). However, in 11 cases (7 males and 4 females) seen in the early phase of the study, the Information subtest had not been administered. Therefore these 11 Verbal IQ's were prorated on the basis of five of the six verbal subtests. Right hand paresis unduly handicapped writing performance in some left-hemisphere damaged patients, so a prorated Performance IQ score was determined for all patients once Digit Symbol scores were eliminated. Nine aphasics (8 males and 1 female) were untestable on Verbal IQ measures because of severe speech production deficits, and 4 aphasics (3 males and 1 female) and 1 right-damaged male were not given the Performance subtests.

IV. Verbal Memory (Wechsler Memory Scale)

The Paired Associate and Logical Stories subtests from the Wechsler Memory Scale - Form I (Wechsler & Stone, 1945) were chosen to measure new learning and immediate recall of verbal material. Stories were scored verbatim (rather than by ideas) according to detailed criteria, where half points were allotted for partially correct responses. Patients were told that they should repeat the stories, "just as I told them to you". The mean of the two stories was recorded (maximum = 23). Instructions for and scoring of Paired Associates was according to the manual (Wechsler & Stone, 1945).

After a delay of approximately 45 minutes (filled with WAIS subtests), without warning, patients were asked to recall again the stories and the ten items from the Paired Associate list. The stories were scored according to the immediate recall criteria, but a full point was given for each word in the paired associate list. A Delayed Verbal score was then calculated by adding the mean of the two stories to the number correct out of 10 on Paired Associates (Milner, 1975).

RESULTS

I. Incidence of Aphasia

The Schuell aphasia data (i.e., the Minnesota Test for the Differential Diagnosis of Aphasia) were collected on 45 left-hemisphere damaged patients and 20 right-hemisphere damaged patients of the original 92 in the sample. Using the cut-off score of 87/90 or less, 36 percent (16/45) of the left brain-damaged patients were classified as "aphasic", whereas no right-hemisphere damaged patient was so classified. Neither did the 20 right-damaged patients who were not tested on the Schuell show obvious clinical signs of aphasia.

Further examination of the left-hemisphere group, however, revealed a marked difference in the sex composition of the aphasic subsample. That is, 48 percent (14/29) of the males compared with only 13 percent (2/16) of the females with left-hemisphere damage fell into the aphasic category ($X^2 = 5.76$, 1 df, $p<.02$). This striking difference in the proportion of male versus female aphasics has not been previously reported in unilaterally brain-damaged populations.

II. Degree of "Dysphasia"

Of the original 92 patients, 42 left-hemisphere damaged and 32 right-hemisphere damaged cases were tested on all Expressive and Receptive tasks. In Table III the raw scores have been converted to percentage correct. Separate three way analyses of variance were performed on the raw data for the combined Expressive and Receptive scores, and for each score individually. The factors were: Laterality of lesion (left, right), Sex (male, female) and Etiology (vascular, tumor). Significant Laterality effects were found for Expressive plus Receptive scores ($F = 12.2$, 1,67 df, $p<.001$); for Expressive scores ($F = 12.1$, 1,67 df, $p<.001$); and for Receptive scores ($F = 9.9$, 1,67 df, $p<.003$). No Sex or Etiology effects (or interactions) reached the .05 level of significance.

Despite the lack of significant sex findings, it is of interest to look at the frequency distribution of the scores within male and female groups. The combined Expressive plus Receptive scores are graphed in Figure 1 for the original 74 cases, plus one new aphasic female (marked X) with a strictly left-hemisphere vascular lesion who was seen at the Royal Victoria Hospital in Montreal. Although she was not administered the Schuell (and is not included in the incidence data previously reported), her expressive skills were limited to the word, "no", thus she undoubtedly would be classified as aphasic, if tested.

Figure 1 demonstrates that after left-hemisphere damage, scores obtained by males more closely approximate a normal bell-shaped distribution, in contrast to females, who appear more bimodally distributed at the extreme ends of the scale. Further-

TABLE III

Expressive and Receptive Dysphasia Scores
(Percent Correct)

	(N)	Expressive and Receptive	Expressive	Receptive
Left damage: Male	(24)	66%	63%	70%
Left damage: Female	(18)	74%	72%	76%
Right damage: Male	(18)	86%	84%	89%
Right damage: Female	(14)	82%	82%	82%

Figure 1

Frequency distribution of Expressive plus Receptive scores where ● = aphasics; O = non-aphasics, and X = female aphasic not included in original analysis.

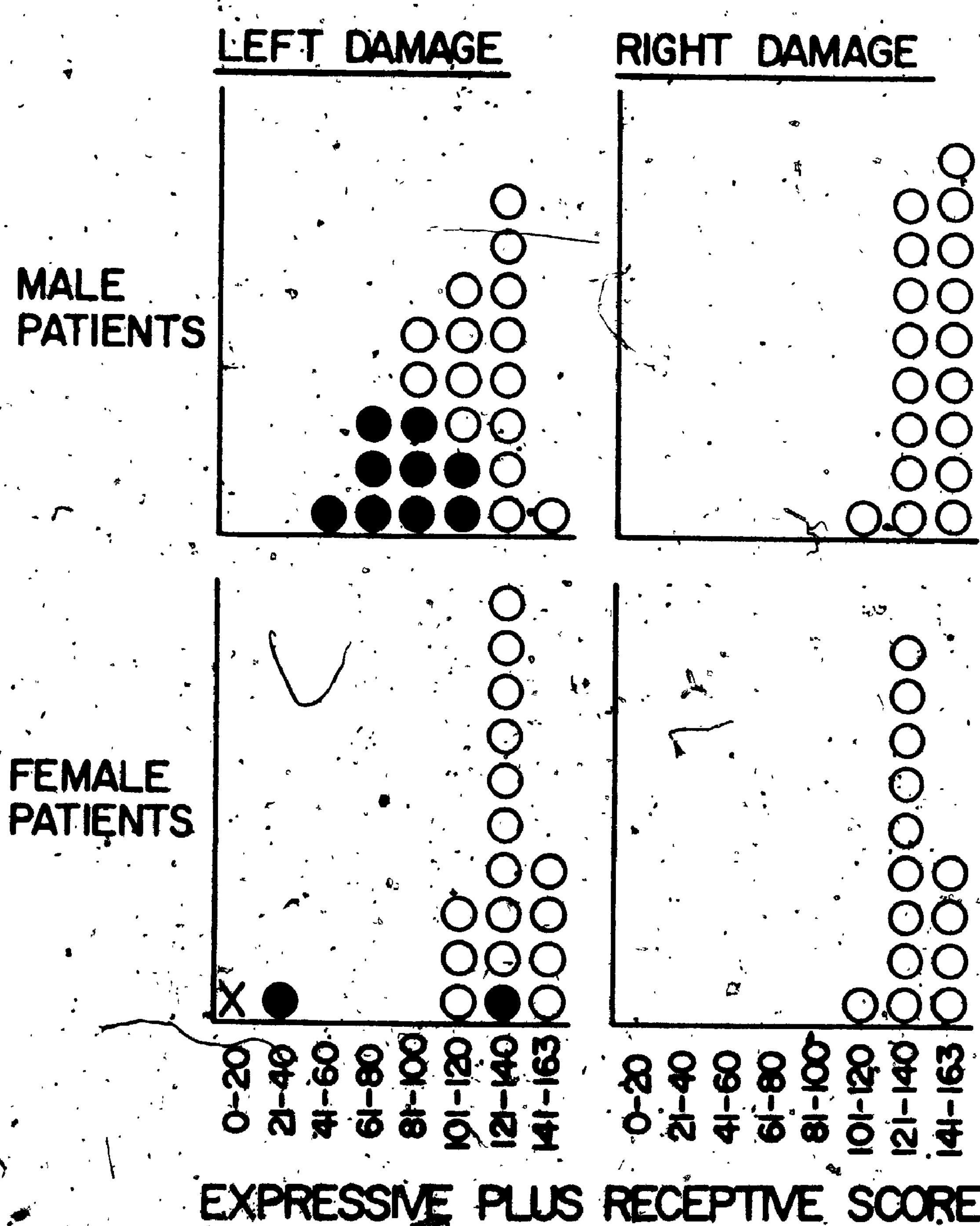

LEFT DAMAGE
RIGHT DAMAGE
MALE PATIENTS
FEMALE PATIENTS
X
0-20
21-40
41-60
61-80
81-100
101-120
121-140
141-163
0-20
21-40
41-60
61-80
81-100
101-120
121-140
141-163
EXPRESSIVE PLUS RECEPTIVE SCORE

FIGURE I

more, the probability that all three scores of the aphasic females should lie outside the range of scores obtained by the 9 male aphasics is .055 on the Runs test (Siegel, 1956).

Figure 1 also demonstrates that aphasics generally performed worse than non-aphasics on the Expressive and Receptive speech tasks. Given the disproportion of male to female aphasics in the left-hemisphere sample, further statistical analyses of verbal intelligence and memory scores excluded all aphasics from the left-hemisphere groups. Since sex differences were expected on an a-priori basis, t tests (two-tailed) were used to examine interactions with sex. The 1% level of probability was adapted as a conservative indication of a significant difference between means.

III. Verbal Intelligence

The Verbal IQ scores graphed in Figure 2 were obtained from 31 left-hemisphere damaged non-aphasics, 39 right-hemisphere damaged patients, and 15 control subjects. Even with aphasics removed from the sample, the left-damaged group ($\bar{X} = 93.4$) obtained significantly lower Verbal IQ scores than the right-damaged group ($\bar{X} = 105.4$, $F = 6.78$, 1,62 df, $p<.01$). However, a highly significant interaction between Sex and Laterality factors ($F = 12.15$, 1,62 df, $p<.001$) indicated that left-damaged males scored significantly lower than right-damaged males ($t = 5.60$, 36 df, $p<.001$), but left-damaged females performed at par with

Figure 2

WAIS Verbal IQ scores.

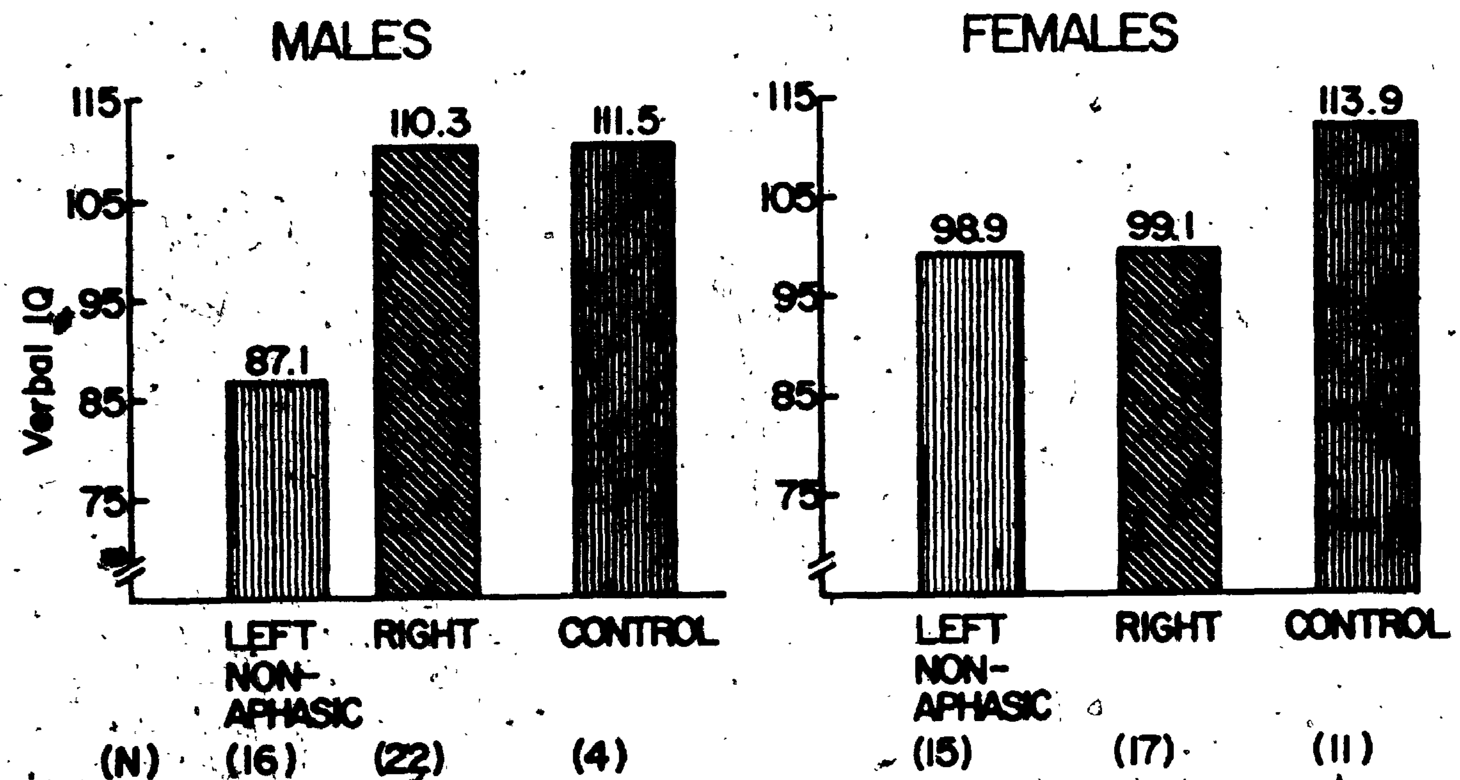

MALES
FEMALES
Verbal IQ
115
105
95
85
75
87.1
110.3
111.5
98.9
99.1
113.9
LEFT NON-APHASIC
RIGHT
CONTROL
(N)
(16)
(22)
(4)
(15)
(17)
(11)

FIGURE II

right damaged females ($t = 0.03$, 31 df, ns).

Because of the small number of normal male controls, no statistical comparisons were made, but it appears (Fig. 2) that right-hemisphere lesions in men did not obviously reduce the Verbal IQ scores relative to controls. Both female groups, however, were significantly impaired relative to female controls (i.e., left non-aphasic females versus controls: $t = 3.36$, 24 df, $p < .01$; right-damaged females versus controls: $t = 2.94$, 26 df, $p < .01$).

Hence, in men, only left-hemisphere lesions were associated with significant Verbal IQ deficits, whereas in women, left- and right-hemisphere lesions were associated with equally mild decrements in Verbal IQ relative to non-brain-damaged controls.

Verbal IQ Subtest Profiles

Naturally the individual subtest scores reflected the same basic findings present in the overall Verbal IQ results; that is, patients with left-hemisphere lesions performed more poorly than patients with right hemisphere lesions, and these laterality effects were more marked in males. What is interesting however, is that the shapes of the subtest profiles showed considerable variation after left-sided lesions depending on the sex of the patient.

Figure 3 shows the age-corrected subscale means for patients given all six verbal subtests. The 6 testable left-damaged male aphasics scored lower than the 13 non-aphasic males, but the profile shapes of the aphasic and non-aphasic males were almost identical. The Similarities subtest appeared particularly sensitive to left-hemisphere lesions in both male groups. The subscale profile of the 12 nonaphasic females differed from those of the male groups in overall superiority (except for Arithmetic), and also in pattern. For example, in females the Similarities mean was not obviously lower than the mean of any other subscale. Only one aphasic female was testable. Although her scores are not graphed in Fig. 3, the shape of her subtest profile was unique, with the lowest subtest being Comprehension and the highest subtest being Information. These data must be interpreted with caution since they are based on rather small numbers and thus have not been statistically analyzed, but they raise the possibility that the components of verbal intelligence may be differentially affected by left-hemisphere damage in men than in women.

After right-sided lesions, Verbal IQ subtest means (age-corrected) ranged from 9.2 to 10.0 in 16 females, and ranged from 11.3 to 12.4 in 17 males (i.e., patients given all subtests). Thus, the shapes of the subtest profiles were relatively flat for both sexes, indicating little variability among the different components of verbal intelligence after right-hemisphere damage.

Figure 3

WAIS Verbal IQ subtest scores (age corrected) for ♂ = left non-aphasic males (n=13); ♂ = left aphasic males (n=6); and ♀ = left non-aphasic females (n=12).

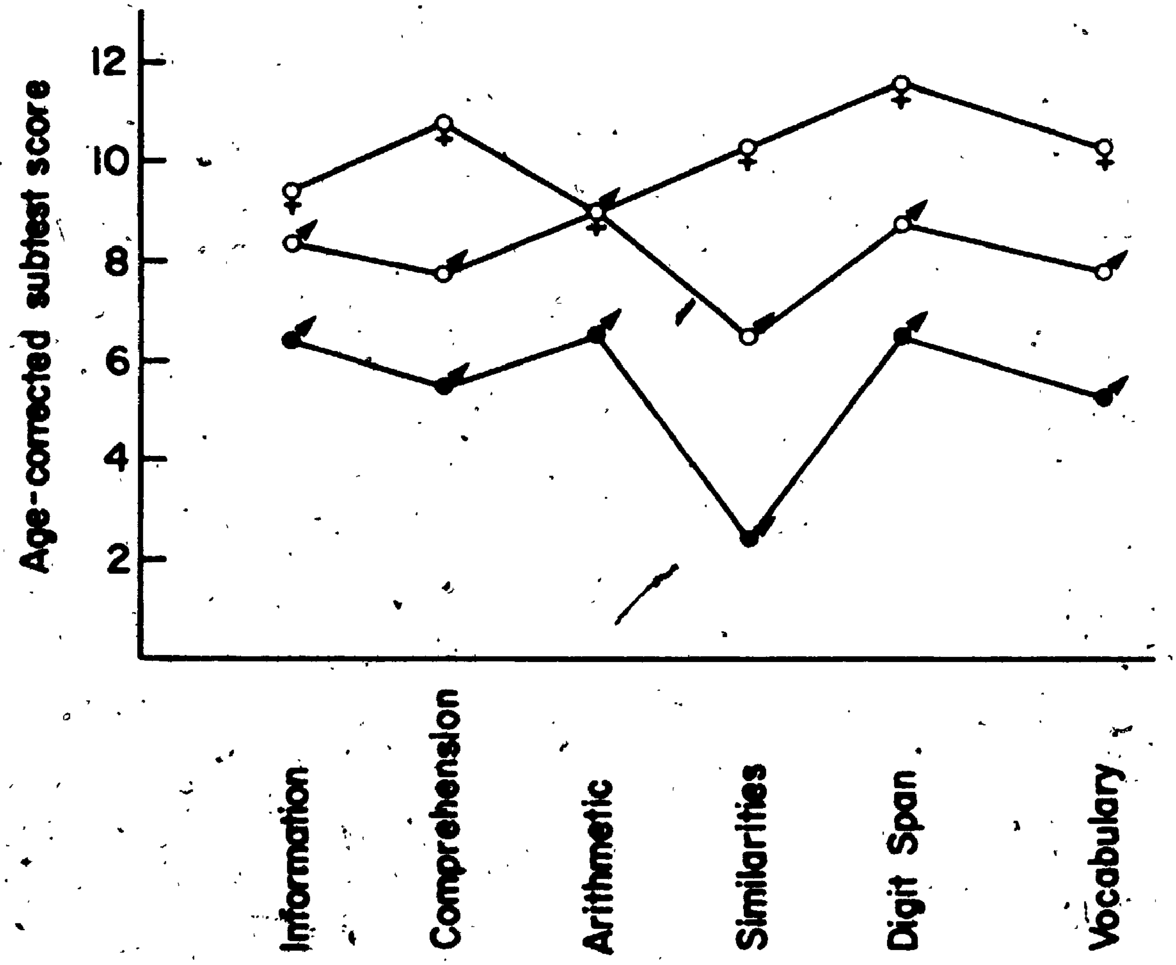

Age-corrected subtest score
12
10
8
6
4
2
Information
Comprehension
Arithmetic
Similarities
Digit Span
Vocabulary

FIGURE III

Performance IQ

The mean Performance IQ for males with left-hemisphere lesions (including aphasics) was 98.0; males with right-hemisphere lesions scored 94.5; females with left-hemisphere lesions scored 97.4; and females with right-hemisphere lesions scored 94.0. Performance IQ did not differ significantly according to Laterality of the lesion ($F = 0.7$, 1,77 df, ns) or Sex ($F = 0.01$, 1,77 df, ns), nor was there a significant interaction between these two factors ($F = 0.01$, 1,77 df, ns). Including the Digit Symbol subtest in the Performance IQ scores did not alter the results in any way. Thus, the depressed verbal abilities found here in men with left-hemisphere damage are not merely a consequence of generalized intellectual deterioration.

IV. Verbal Memory

Thirty-two non-aphasic left-damaged patients and 37 right-damaged patients were given the Wechsler Memory Scale subtests. The results presented in Table IV clearly indicate that only the men showed obvious verbal memory deficits after left-hemisphere lesions, but not the women.

Separate analyses of variance found significant Laterality effects for Immediate Recall of Stories ($F = 9.8$, 1,61 df, $p<.003$); Paired Associate Learning ($F = 6.5$; 1,61 df, $p<.01$); and Delayed Verbal Recall ($F = 10.4$, 1,59 df, $p<.003$). Women scored better overall than men on Paired Associates ($F = 11.4$, 1,61 df, $p<.002$).

TABLE IV

Verbal Memory Scores (Wechsler Memory Scale)

	(N)	Left Damage: Non-Aphasics	(N)	Right Damage	Probability Level	
Immediate Story Recall						
Male	(17)	3.9	(21)	7.8	.001	(t=4.5, 36 df)
Female	(15)	6.2	(16)	6.8	NS	(t=0.8, 29 df)
Paired Associates						
Male	(17)	7.9	(21)	13.3	.001	(t=4.0, 36 df)
Female	(15)	13.7	(16)	14.5	NS	(t=0.6, 29 df)
Delayed Verbal						
Male	(17)	6.4	(21)	12.6	.001	(t=5.0, 36 df)
Female	(14)	10.2	(15)	12.3	NS	(t=1.6, 27 df)

Most interesting were the Sex by Laterality interactions on Immediate Recall of Stories (F = 5.28, 1,61 df, $p<.02$); Paired Associate Learning (F = 6.76, 1,61 df, $p<.01$); and Delayed Verbal Recall (F = 8.28, 1,59 df, $p<.006$). Further <u>t</u> test comparisons contained in Table IV showed that men with left-hemisphere lesions (non-aphasics) obtained significantly lower verbal memory scores than men with right-hemisphere lesions ($p<.001$ in each comparison). In females, a left-hemisphere lesion did not reduce verbal recall scores significantly on any memory task.

Age-corrected norms for the Wechsler Memory Scale subtests were unavailable, thus further comparisons between patients and controls were deemed inappropriate given the large discrepancies in age.

<u>The Effects of Etiology</u>

It is crucial to emphasize that etiological factors did not account for the sex differences in verbal deficits after unilateral brain damage. First of all, none of the data analyses found a significant main effect due to etiology, nor did etiology interact with sex or laterality variables on any measure.

However since the four sex by laterality groups in Table I varied somewhat in source of pathology, the results were re-examined for the vascular and the tumor groups separately. Aneurysm cases and hemorrhages have been removed from these analyses, and aphasic patients were also excluded.

The mean scores on all verbal tasks are presented by sex and laterality group in Table Va (vascular) and Vb (tumors). Results based on either the vascular group or the tumor group were consistent with the previously reported findings based on the combined etiological groups. That is, verbal deficits appeared most clearly in men with left-hemisphere damage (non-aphasics).

Severity and Locus of Lesion

Severity and locus of the cerebral lesion are two critical factors which can affect both incidence and type of language deficit after left hemisphere damage (Benson, 1967; Milner, 1975). Thus it is important to know whether the differences in verbal abilities found between males and females with left hemisphere damage were related to concomitant differences in either severity or locus of cerebral damage.

Precise neuroanatomical delineation of the lesions via autopsy data was unavailable, hence neurological signs were used to estimate amount of left-sided tissue damage. There were no significant differences between men and women with left-sided lesions in incidence of visual field defects or hemiparesis (Table II). An index of severity of hemiparesis was obtained in all but 1 male and 1 female by comparing the proportion of right hemiparetics still showing superior right-hand strength on a Lafayette dynamometer. In male patients with clinically detectable weakness affecting the right arm or leg, 22.2 percent (4/18)

TABLE Va

Results of Vascular Cases (non-aphasics) -
Infarcts Only

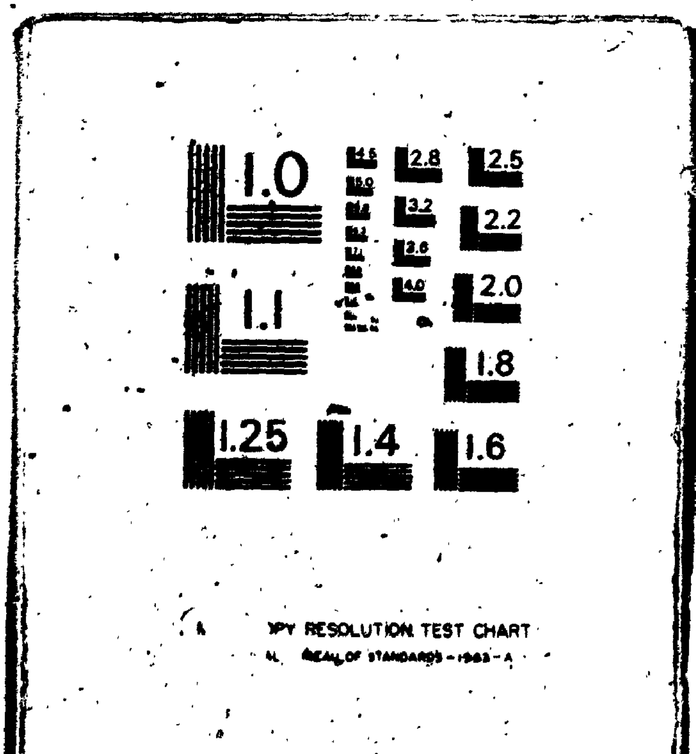
	(N)	Left Damage	(N)	Right Damage
Age				
Male	(11)	53.9	(12)	47.3
Female	(8)	53.5	(9)	50.2
Expressive & Receptive				
Male	(10)	75%	(9)	87%
Female	(7)	83%	(7)	79%
Verbal IQ				
Male	(11)	88.4	(12)	113.2
Female	(8)	98.3	(8)	98.3
Logical Stories				
Male	(11)	3.9	(12)	7.4
Female	(8)	6.3	(8)	6.5
Paired Associates				
Male	(11)	8.1	(12)	14.3
Female	(8)	14.0	(8)	14.0
Delayed Verbal				
Male	(11)	6.6	(12)	13.1
Female	(8)	11.4	(8)	12.5

TABLE Vb

Results of Tumor Cases Only (non-aphasics)

	(N)	Left Damage	(N)	Right Damage
Age				
Male	(6)	58.3	(10)	44.8
Female	(6)	42.5	(3)	46.0
Expressive & Receptive				
Male	(4)	75%	(7)	87%
Female	(6)	85%	(2)	88%
Verbal IQ				
Male	(5)	84.2	(9)	106.7
Female	(6)	106.0	(3)	96.3
Logical Stories				
Male	(6)	3.9	(8)	7.1
Female	(6)	6.3	(3)	6.6
Paired Associates				
Male	(6)	7.4	(8)	11.0
Female	(6)	14.3	(3)	12.2
Delayed Verbal				
Male	(6)	5.8	(8)	11.8
Female	(5)	10.8	(3)	9.0

2 OF/DE 2



maintained superior right grip strength compared to 14.3 percent (1/7) of the females. These proportions were not significantly different ($X^2 = 0.04$, 1 df, Yates correction). Thus, extent of the tissue damage as reflected in the incidence and/or severity of neurological signs (other than aphasia) appeared to be similar in left-hemisphere damaged males and females. If anything, females tended to be more impaired than males on these clinical measures.

To further ascertain comparable localization of left-sided lesions in males and females (i.e., beyond that already provided by neurological signs), the author carefully read all brain scan and EEG reports contained in the medical charts. Only the EEG findings were used for localization purposes because a large proportion of the brain scans were normal (32%), and were not categorized by lobe.

EEG reports were classified as follows: (1) anterior to Rolandic fissure only, (2) posterior to Rolandic fissure only, (3) generalized (no focal or multifocal abnormalities), (4) other (both anterior and posterior regions of temporal lobe or central gyri), and (5) normal. EEG information was available for 81% of the males and 75% of the females with left-sided damage, with positive findings reported in 81% of the males and 83% of the females. Anterior foci occurred in 33% (7/21) of males compared to 17% (2/12) of females, whilst strictly posterior lesions occurred in 5% (1/21) of males and 25% (3/12) of females. X^2 analysis on the raw data showed these trends were not significant (X^2 = 1.41, 1 df, Yates correction). Generalized, other and normal recordings occurred in more equal proportions in men (33%, 5% and 24%, respectively) and women (25%, 16% and 17%, respectively).

These EEG estimates of lesion localization among left-damaged patients suggested that more males than females had anteriorly placed lesions, whereas the reverse was found for posterior EEG abnormalities. Although these trends were not significant, nevertheless it should be made clear that within each of the three major EEG localization categories (anterior, posterior and generalized), males consistently performed worse than females on verbal tasks. Therefore minor discrepancies between males and females in the locus of left-hemisphere damage cannot account for the reported sex differences in incidence or degree of verbal deficits.

DISCUSSION

This investigation has demonstrated that verbal deficits subsequent to unilateral brain-damage depend to a significant degree on the sex of the patient as well as on the side of the lesion. All types of language impairments were either greatly diminished or absent in females with left-sided lesions. Most notably, aphasia associated with left-hemisphere damage occurred three times more often in males compared to females. But even when aphasics were removed from the left-hemisphere groups, verbal deficits in intellectual and memory tasks continued to be more salient in males than in females. On the other hand, after right-hemisphere damage, only women showed mildly depressed verbal intelligence relative to normal controls.

These sex-dependent verbal asymmetries were not reducible to differences between males and females in age, education, etiology, length of illness, incidence of familial sinistrality or the differential occurrence of unilateral weakness and/or visual field defects. None of these factors differed significantly between males and females within each laterality group. Estimates of the severity and locus of left-sided lesions also failed to account for the marked verbal deficits seen in males. Nor was there a tendency for males to show more global cognitive impairments than females since nonverbal intelligence did not differentiate among patient groups.

The most probable explanation for these findings [illegible] that the cerebral organization for speech and language functions differs between men and women, possibly along more than one dimension. Specifically, the results of this investigation suggest that sex differences may exist: (1) in degree of bilateral speech representation; and/or (2) in regional specialization of verbal functions within the left hemisphere. These possibilities, as well as some others, will be discussed with additional material from the literature on sex differences in functional brain asymmetry.

Sex Differences in Bilateral Speech Representation

A greater degree of bilateral speech representation in women would predict that speech disorders should be more severe in right-handed males than in right-handed females following a left-sided brain lesion. In accordance with this hypothesis, the present investigation found that severe speech dysfunction (i.e., aphasia) occurred significantly more often in men than in women. Similarly, verbal intelligence deficits and verbal memory loss after left-hemisphere damage were more marked in male than in female non-aphasics.

Bilateral speech representation in females would predict not only milder speech disorders in women, but also a higher occurrence of language difficulties after right-hemisphere damage than in males. In fact, Verbal IQ scores were impaired, relative to normal controls, after both right- and left-sided damage in women. Given that the educational background of female patients was comparable to that of normal controls, and given that educational level is highly predictive of intellectual level (Matarazzo, 1972), it follows that the premorbid intellectual level of the female patients approximated that of controls. If this is true, then in females, verbal intelligence was equally (though minimally) depressed after lesions of either hemisphere, a pattern supporting some degree of bilateral speech organization in women. On the other hand, the male pattern of verbal intellectual loss restricted to left-hemisphere damage indicates more lateralized (i.e., left-hemisphere) control of verbal functions in men.

Because no attempt was made in this study to test patients immediately on admission to hospital or again at regular intervals thereafter, it is not known whether recovery of language functions proceeded more readily in females than in males, as one might expect if speech were bilaterally represented in females. Nevertheless, if future research were to systematically demonstrate that just as many females as males showed signs of aphasia in the initial stages of their disease, then the finding of fewer aphasic females in this study would suggest that language disorders may recover more quickly in females than in males.

The incidence of right-hemisphere cerebral dominance for basic speech functions, however, showed no obvious sex difference in this sample. Thus, despite the mild verbal intellectual deficits found in females with right-hemisphere damage, no right-damaged female (or male) was classified as aphasic. Other large scale studies have reported that aphasia associated with right cerebral lesions or injection of sodium amytal into the right internal carotid artery occurred in fewer than 5 percent of right-handers without early left-hemisphere damage (Milner, 1975; Penfield & Roberts, 1959). Unfortunately, these investigations did not identify by sex those patients with right-hemisphere speech representation.

Thus, except for the occasional case study (for examples see Lake & Bryden, 1976), no convincing data can be found to support the idea that right-handed females have a greater tendency toward strictly right-hemisphere cerebral dominance for basic speech processes. But because this conclusion is based on lack of data rather than on positive evidence, it should be viewed with caution until larger samples of right-handed male and female aphasics with right-hemisphere lesions have been compared.

Both clinical and normative studies relevant to this issue are surprisingly consistent in supporting the idea that the left hemisphere is more specialized for verbal functions in males than in females. For example, Lansdell (1961; 1973) has reported that verbal intellectual skills (i.e., proverb interpretation and word association) were unaffected by unilateral temporal lobe excisions in females, whereas males showed the expected verbal deficits after left- but not right-sided damage.

When cerebral lateralization for verbal processes is inferred in normal adults on the basis of dichotic listening or tachistoscopic techniques, several studies have indicated that right-handed females showed more symmetrical representation of verbal functions than did right-handed males. It is generally accepted that the perceptual asymmetries found between the left and right ears (dichotic presentation) or visual fields (tachistoscopic presentation) reflect greater specialization in the hemisphere contralateral to the superior side (Kimura, 1973). Lake and Bryden (1976) reported that 74 percent of right-handed males in contrast to 57 percent of right-handed females showed the usual pattern of superior right-ear scores on a verbal dichotic task. Moreover, the difference in accuracy between the two ears (i.e., the degree of asymmetry favouring the right ear) was significantly larger in men than in women. Similar findings were reported by Harshman et al. (1976). Additionally, right visual field superiorities in the report of verbal material presented tachistoscopically have been more clearly seen in males than in females (Ehrlichman, 1971; Hannay & Malone, 1976; Levy & Reid, 1976).

Recent anatomical studies of human brain structures known to participate in speech production (i.e., frontal operculum) and auditory speech perception (i.e., planum temporale) also show sexual differentiation in degree of asymmetry. Overall, the left planum temporale is larger than the right (Geschwind & Levitsky, 1968; Teszner et al., 1972; Wada et al., 1975), whereas the right frontal operculum is larger than the left (Wada et al., 1975). Exceptions to these directional trends were found significantly more often in females than in males (Wada et al., 1975), thus offering an anatomical correlate for greater functional symmetry in females.

In summary, when sex differences are reported, the available clinical, normative and anatomical data suggest that the neural mechanisms underlying speech functions may be less asymmetrically controlled in adult females than in males. However, it is not known to what extent bilateral control of verbal functions is based on differences in intrahemispheric organization or differences in interhemispheric connections, or both. It is interesting to speculate (Bogen et al., 1972; Lansdell & Davie, 1972) that cortical and subcortical fibres connecting the left and right halves of the brain may differ between men and women in type, number, efficiency or directional routing. If present, these differences may have functional significance for the subsequent lateralization of speech (and nonspeech) processes.

Less speculative, perhaps, is the idea that there are sex differences in the intrahemispheric organization of speech functions. From the present study, it appears that the right hemisphere in females has greater control over certain verbal functions than does the right hemisphere in males. Additional evidence from this study suggests that speech organization within the left hemisphere also differs according to sex.

Sex Differences in Left Hemisphere Organization of Speech Functions

Given that the locus and extent of tissue damage were fairly comparable across male and female left-damaged groups, the qualitative differences in verbal behavior between left-damaged men and women raise the possibility of sex differences in the underlying neural organization of speech processes within the left hemisphere. For example, on "Expressive and Receptive" verbal tasks, scores obtained by male aphasics were more homogeneous than scores obtained by female aphasics. Secondly, the shapes of Verbal IQ subtest profiles differentiated male and female non-aphasics with left hemisphere lesions, indicating that the several components of verbal intelligence were not equally affected in males and females.

Data from other sources would predict that where speech functions are restricted to one hemisphere, regional specialization within the dominant hemisphere is likely to be different from those cases in which speech functions are less lateralized. For example, Benson (1967) could differentiate fluent from non-fluent aphasics on the basis of anterior versus posterior abnormalities on brain scan parameters in a sample of 100 right-handed men with left brain damage. However, in a smaller group of left-handed aphasics with left-hemisphere damage, for whom it was assumed that speech was less lateralized, no orderly anterior-posterior correlate of aphasia typology emerged.

Unfortunately other clinical studies which have clearly demonstrated dissociable types of verbal deficits according to anatomical locus of the brain lesion have failed to delineate the role of sex differences as they either contained men only (Benson, 1967) or just omitted to report the data separately for males and females (Milner, 1975). Nor can data from the present study effectively address the question of hemispheric regional specialization since the nature of the pathology in this patient sample (tumor and vascular) insured that damage was neither lobe specific nor confined to cortical grey matter. Future research, then, should not ignore possible sex differences in localization of speech functions within the left hemisphere (i.e., diffuse representation versus regional specialization, or cortical versus subcortical representation).

Not only is left-hemisphere specialization for verbal functions more clearly seen in adult males, but it has been suggested that right-hemisphere specialization for visuo-spatial ability is more consistently found in men than in women (Kimura, 1969; McGlone & Davidson, 1973; McGlone & Kertesz, 1973). In the present investigation, patients were also administered visuoconstructional and perceptual tasks such as the Block Design subtest of the WAIS, a mental rotation test fashioned after Thurstone's Spatial Relations test (Thurstone, 1938) and an immediate memory task for photographed faces. The results of each task indicated that men with right-hemisphere damage scored significantly lower than men with left-hemisphere damage (non-aphasic sample), but females with left- or right-sided lesions performed equally well (McGlone, in preparation).

Thus, in the same sample of patients in which there was greater left-hemisphere specialization for verbal functions in males compared to females, there was greater right-hemisphere specialization for spatial functions in males compared to females. It would appear entirely warranted, then, to conclude that asymmetrical specialization of the two cerebral hemispheres is less characteristic of adult female right-handers than adult male right-handers (McGlone, 1976).

The most parsimonious interpretation of the available data on sex differences in brain asymmetry would be that males, as a group, are less variable than females with respect to the cerebral organization of speech (and non-speech) functions. If members of the male right-handed population tend to be more like each other with respect to patterns of brain lateralization, it follows that consistent patterns of brain organization will appear across various samples of males. In right-handed females, consistent patterns of perceptual or cerebral asymmetries would occur with far less frequency across individuals and across samples.

That some degree of bilateral speech representation was more common in adult females than adult males is strongly indicated by the results of this study. Furthermore, the data suggested that increased variability in <u>inter</u>hemispheric representation of speech functions in females may be related to sex differences in <u>intra</u>hemispheric organization of speech functions.

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GENERAL DISCUSSION

The present study showed that both elementary and complex language skills were more severely affected after left-hemisphere lesions in right-handed men than in women. Both left- and right-hemisphere lesions resulted in mild loss of verbal intelligence in women, but not in men, compared to normal controls. These findings were not accounted for by other factors such as age, education, extent, locus or etiology of the lesion, or incidence of familial sinistrality. It was suggested that cerebral representation of speech functions may be more bilaterally organized in adult females than in males.

After right-hemisphere lesions, nonverbal intelligence was impaired, relative to verbal, in men but not in women. It was suggested that males may be more right-hemisphere-dependent than females for nonverbal functions. Overall, degree of hemispheric specialization appeared to be more marked in the adult male than in the female brain.

These findings may have implications for the broader issue of sex differences in overall cognitive ability.

Sex differences in overall verbal and spatial ability

Female superiority on verbal tasks is one of the more solidly established generalizations which continues to be supported in current research (for review see Maccoby, 1966; Maccoby & Jacklin, 1974). It is most clearly seen in the executive aspects of language production rather than in verbal reasoning (Hutt, 1972). In contrast, spatial abilities tend to be better developed in males than in females. This has been demonstrated for locating a point in space, aligning a rod to the vertical, left-right discrimination, constructional skill, identification of patterns presented in unusual orientations, and finding elements of an embedded design in a confusing background (Bakan & Putnam, 1974; Maccoby & Jacklin, 1974; Sandström, 1953).

Genetic, hormonal and environmental factors probably all contribute to sexual differentiation in cognitive ability (see discussion in Maccoby & Jacklin, 1974). It appears that degree of functional brain asymmetry may also be related to overall skill, not only after brain injury, but also in the normal individual.

If greater pre-pathological skill were associated with lesser vulnerability to the effects of brain lesions, then speech deficits should be less severe in women and spatial deficits should be less severe in men. Data from the present study, however, suggested that women were less impaired on both speech and certain spatial functions, except after right-hemisphere lesions which produced mild Verbal IQ loss in women, but not in men relative to controls. It would, thus, appear that no simple relationship exists between the overall pre-pathological level of skill and loss of function subsequent to brain damage.

Bilateral representation of a function appears to increase the probability of mild and less specific cognitive impairments after a unilateral brain lesion, often with quicker recovery of function (Goodglass & Quadfasel, 1954; Subirana, 1958). Under pathological circumstances, then, bilateral functional representation would clearly be advantageous over unilateral representation in preventing severe loss of skills, but this may be of little survival value for the species, since pathology usually takes place after child-bearing years.

In normal brains, however, it has been argued that bilateral representation is less advantageous than unilateral representation (Levy, 1969, 1975). Levy argues that, in solving spatial problems, a perceptual or "holistic" approach may be incompatible with a verbal, sequential analysis of details. Thus, when verbal and nonverbal functions are subserved by the same hemisphere, competition between the different processes occurs, with one function developing at the expense of the other.

Some support for a competition hypothesis was found in reports that left-handers, in whom speech is more bilaterally represented, were impaired relative to right-handers on nonverbal tasks (Levy, 1969; Miller, 1971; Nebes, 1971; Silverman, 1966).

Other investigators, however, were unable to replicate these findings (Gibson, 1973; Hardyck et al., 1976; Newcombe et al., 1975). McGlone and Davidson (1973) found that the pattern of impaired nonverbal ability in left-handers only occurred in those individuals with inferred right-hemisphere speech representation, i.e., higher left-ear scores on a dichotic task.

A brain lateralization model employing a competition hypothesis, may also account for sex differences in spatial ability. The current study suggests greater bilateral representation of verbal and nonverbal functions in women than in men. Hence, overall spatial abilities may not develop to their full potential in women because of the hypothesized interfering effects of bilateral cerebral organization for speech.

McGlone & Davidson (1973) found some support for this idea. The link between inferred right-hemisphere speech representation and impaired spatial ability was significant in women, but not in men (McGlone & Davidson, 1973). Moreover, females showed bilateral spatial representation (inferred from a tachistoscopic dot enumeration task) and poorer spatial ability than males who showed right-hemisphere spatial representation. Hence, competition effects may be maximal in females due to the co-occurrence of bilateral verbal and nonverbal cerebral representation.

The advantage that asymmetrical cerebral representation appears to confer on spatial ability, however, does not hold for verbal functions. If it did, verbal abilities should be better in right-handers than in left-handers, and better in males than in females. In fact, verbal skills do not differ between hand-preference groups (Hardyck et al., 1976; Levy, 1969; Robinson, 1974), and for some language tasks females are superior to males (Maccoby & Jacklin, 1974). Thus, overall verbal ability may not be determined so much by the left-right division of labour in the brain as by other factors.

At some point in the evolution of man, the probability of survival may have depended crucially upon spatial functions. In hunting societies, a division of labour usually existed between the sexes such that males engaged in the hunt, whereas females engaged in home-related activity (Campbell, 1966; Washburn, 1960). The most successful hunters, presumably, were men with the best spatial ability, since navigating unfamiliar territory, remembering spatial locations and on-target aiming of weapons depend upon visuospatial processes. If overall spatial ability depends on degree of cerebral specialization for spatial functions, selection factors would increase the likelihood of asymmetrical representation in men, but not necessarily in women. A genetic component is suggested by the fact that sex-linked spatial ability patterns are present in modern, non-hunting societies, though the mode of inheritance is not yet clear (Garron, 1970; Stafford, 1961). More puzzling, perhaps, is the biological significance of increased verbal ability in females and its possible relation with bilateral cerebral representation.

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APPENDIX 1

Raw data on patients with unilateral brain lesions and non-brain damaged controls.

LEFT-HEMISPHERE DAMAGED MALES (continued)

Subject Number	Etiology	Schuell	Wechsler Intelligence Scale: Verbal IQ	Wechsler Intelligence Scale: Performance IQ	Aphasia Battery: Expressive (max=86)	Aphasia Battery: Receptive (max=77)	Wechsler Memory Scale: Logical Stories	Wechsler Memory Scale: Paired Associates	Wechsler Memory Scale: Delayed Recall
212	V	NA	93	96	60	68	6.8	12.5	8
205	V	NA	90	95	63	64	7.3	14.0	11
222	V	NA	71	75	51	49	1.5	2.0	4
209	V	NA	110	110	75	72	4.8	13.5	8
219	V	NA	93	102	69	60	3.0	5.0	4
218	V	NA	93	121	70	51	4.3	9.5	6
223	V	NA	105	112	62	67	3.8	11.5	10
212	V	NA	71	88	—	—	2.0	5.5	4
214	V	NA	81	118	59	61	2.3	7.0	8
232	T	NA*	99	112	62	63	3.5	4.0	1
233	T	NA	76	82	—	—	2.5	3.0	3
242	T	NA	80	72	64	52	2.5	10.5	5
235	T	NA	84	84	—	—	2.5	7.0	7
234	T	NA	82	92	52	54	5.3	8.0	6
241	T	NA*	—	—	72	73	7.0	12.0	13

LEFT-HEMISPHERE DAMAGED FEMALES

Subject Number	Etiology	Schuell	Wechsler Intelligence Scale Verbal IQ	Wechsler Intelligence Scale Performance IQ	Aphasia Battery Expressive (max=86)	Aphasia Battery Receptive (max=77)	Wechsler Memory Scale Logical Stories	Wechsler Memory Scale Paired Associates	Wechsler Memory Scale Delayed Recall
301	V	A	—	—	0	32	—	—	—
315	V	A	85	69	64	60	2.0	11.0	10
314	V	A*	—	—	0	17	—	—	—
403	V	NA	112	92	—	—	6.0	12.0	11
404	V	NA	93	113	77	67	5.0	11.0	7
408	V	NA	103	107	77	63	6.3	17.5	7
413	V	NA	101	113	68	63	9.0	16.5	15
405	V	NA	85	75	59	46	4.0	6.0	2
406	V	NA	92	109	76	57	2.5	18.5	11
402	V	NA	93	102	65	52	6.3	13.5	10
407	V	NA	107	96	73	74	9.3	11.0	16
410	V	NA*	85	79	62	68	6.3	12.0	12
401	T	NA	94	73	71	59	4.3	7.0	5
412	T	NA	97	103	71	56	6.5	16.0	9
414	T	NA	114	116	78	71	6.8	18.5	14
416	T	NA	115	117	82	77	4.5	17.5	12
417	T	NA	113	99	65	72	8.3	19.0	14
415	T	NA	103	115	67	63	7.5	7.5	—
423	T	NA*	78	83	58	48	—	—	—
418	T	NA*	110	93	62	67	—	—	—

RIGHT-HEMISPHERE DAMAGED MALES

Subject Number	Etiology	Schuell	Wechsler Intelligence Scale: Verbal IQ	Wechsler Intelligence Scale: Performance IQ	Aphasia Battery: Expressive (max=86)	Aphasia Battery: Receptive (max=77)	Wechsler Memory Scale: Logical Stories	Wechsler Memory Scale: Paired Associates	Wechsler Memory Scale: Delayed Recall
509	V	NA	104	107	75	61	7.5	16.0	14
513	V	NA*	127	79	69	73	8.0	17.0	16
511	V	NA	117	97	73	77	5.0	17.0	13
507	V	NA*	72	75	—	—	3.3	6.0	4
501	V	NA*	134	141	—	—	13.8	16.5	22
502	V	NA	140	94	78	75	8.0	12.5	11
512	V	NA*	115	106	72	59	9.0	16.5	15
503	V	NA	109	70	68	75	8.5	19.5	13
508	V	NA*	105	76	58	52	5.3	13.5	11
506	V	NA*	107	83	66	71	5.8	14.5	12
510	V	NA	113	124	77	66	10.0	14.0	17
504	V	NA*	118	113	80	71	4.0	13.0	10
505	V	NA	106	63	69	65	8.8	15.0	12
601	T	NA*	87	—	57	—	—	—	—
608	T	NA	97	81	70	61	4.0	8.5	7
607	T	NA*	—	—	66	63	7.5	7.0	8
602	T	NA*	75	79	52	—	2.3	8.0	7
603	T	NA*	120	105	68	71	9.0	10.0	12
606	T	NA	115	84	71	73	9.0	13.5	16
604	T	NA*	107	83	—	—	—	—	—
609	T	NA	129	121	80	77	7.5	9.5	10
610	T	NA	124	118	81	76	8.8	18.0	17
605	T	NA	106	103	71	59	9.0	13.5	17

RIGHT-HEMISPHERE DAMAGED FEMALES

Subject Number	Etiology	Schuell	Wechsler Intelligence Scale Verbal IQ	Performance IQ	Aphasia Battery Expressive (max=86)	Receptive (max-77)	Wechsler Memory Scale Logical Stories	Paired Associates	Delayed Recall
704	V	NA	95	89	69	60	5.5	16.5	13
709	V	NA	82	83	60	51	5.5	13.5	13
702	V	NA*	85	80	67	59	6.5	16.5	—
703	V	NA*	128	105	—	—	6.0	15.0	10
708	V	NA*	94	94	—	—	—	—	—
713	V	NA	99	97	80	68	7.0	17.5	12
705	V	NA*	114	89	72	60	9.0	19.0	18
714	V	NA*	88	91	67	54	8.5	10.0	13
706	V	NA*	100	112	78	67	4.5	13.0	10
711	V	NA	117	78	67	69	12.5	15.5	20
712	V	NA	113	100	66	68	8.3	15.0	13
710	V	NA	99	109	74	70	6.5	16.0	15
707	V	NA	101	113	65	66	6.0	16.0	11
701	V	NA	80	76	69	63	3.3	12.5	10
801	T	NA*	80	79	—	—	4.3	9.5	8
802	T	NA*	104	86	79	69	5.5	14.5	10
803	T	NA	105	110	75	64	10.0	12.5	9

CONTROLS: MALES

Subject Number	Etiology	Schuell	Wechsler Intelligence Scale Verbal IQ	Wechsler Intelligence Scale Performance IQ	Aphasia Battery Expressive (max=86)	Aphasia Battery Receptive (max=77)	Wechsler Memory Scale Logical Stories	Wechsler Memory Scale Paired Associates	Wechsler Memory Scale Delayed Recall
001	—	—	114	111	—	—	6.0	9.5	8
002	—	—	112	102	—	—	4.5	14.5	8
003	—	—	94	111	—	—	5.5	7.0	7
004	—	—	126	136	—	—	9.8	12.0	14

CONTROLS: FEMALES

Subject Number	Etiology	Schuell	Wechsler Intelligence Scale Verbal IQ	Wechsler Intelligence Scale Performance IQ	Aphasia Battery Expressive (max=86)	Aphasia Battery Receptive (max=77)	Wechsler Memory Scale Logical Stories	Wechsler Memory Scale Paired Associates	Wechsler Memory Scale Delayed Recall
005	—	—	116	108	—	—	9.0	18.0	15
006	—	—	135	123	—	—	7.3	15.0	12
007	—	—	119	117	—	—	8.5	14.5	14
008	—	—	125	111	—	—	7.5	13.9	14
009	—	—	107	116	—	—	6.5	12.0	13
010	—	—	118	114	—	—	6.5	15.0	14
011	—	—	110	120	—	—	7.5	12.5	12
012	—	—	95	123	—	—	7.0	19.5	17
013	—	—	98	114	—	—	4.5	10.5	9
014	—	—	122	118	—	—	10.8	15.0	20
015	—	—	108	103	—	—	6.0	11.0	8